Sub-Indicator: Coastal Wetland Birds

Overall Assessment

Status (based on data from 2021 to 2023): Fair

10-Year Trend (2013–2023): No Trend

Long-term Trend (1995–2023): Undetermined

Rationale: Status and trends are based on the Index of Biotic Condition (IBC), a bird-based index of wetland health. Annual median IBC in coastal wetlands in the Great Lakes overall ranged from 1.9 (2012) to 2.8 (2020) out of 10 from 2011 to 2023, and did not significantly improve or deteriorate over the past 10 years (2013–2023) despite some annual increases and decreases in between. Median IBC was 2.3 based on data from 2021 to 2023, which is within the defined range for Fair status: 2.0 ≤ median IBC ≤ 3.9.

Lake-by-Lake Assessment

Lake Superior

Status (based on data from 2021 to 2023): Fair

10-Year Trend (2013–2023): No Trend

Long-term Trend (1995–2023): Undetermined

Rationale: Annual median IBC in coastal wetlands in Lake Superior ranged from 1.4 (2019) to 2.3 (2021) out of 10 from 2011 to 2023, and did not significantly improve or deteriorate over the past 10 years (2013–2023) despite some annual increases and decreases in between. Median IBC was 2.0 based on data from 2021 to 2023, which is within the defined range for Fair status: 2.0 ≤ median IBC ≤ 3.9.

Lake Michigan

Status (based on data from 2021 to 2023): Fair

10-Year Trend (2013–2023): No Trend

Long-term Trend (1995–2023): Undetermined

Rationale: Annual median IBC in coastal wetlands in Lake Michigan ranged from 1.1 (2014) to 3.1 (2020) out of 10 from 2011 to 2023, and did not significantly improve or deteriorate over the past 10 years (2013–2023) despite some annual increases and decreases in between. Median IBC was 2.4 based on data from 2021 to 2023, which is within the defined range for Fair status: 2.0 ≤ median IBC ≤ 3.9.

Lake Huron (including St. Marys River)

Status (based on data from 2021 to 2023): Fair

10-Year Trend (2013–2023): No Trend

Long-term Trend (1995–2023): Undetermined

Rationale: Annual median IBC in coastal wetlands in Lake Huron ranged from 2.0 (2012) to 3.0 (2018) out of 10 from 2011 to 2023, and did not significantly improve or deteriorate over the past 10 years (2013–2023) despite

some annual increases and decreases in between. Median IBC was 2.3 based on data from 2021 to 2023, which is within the defined range for Fair status: 2.0 ≤ median IBC ≤ 3.9.

Lake Erie (including St. Clair-Detroit River Ecosystem)

Status (based on data from 2021 to 2023): Fair

10-Year Trend (2013–2023): No Trend

Long-term Trend (1995–2023): No Trend

Rationale: Annual median IBC in coastal wetlands in Lake Erie ranged from 1.6 (2001) to 3.5 (2009) from 1995 to 2023, and did not significantly improve or deteriorate over the past 10 years (2013–2023) despite some annual increases and decreases in between, or over the long term (1995–2023). Median IBC was 2.3 based on data from 2021 to 2023, which is within the defined range for Fair status: 2.0 ≤ median IBC ≤ 3.9.

Lake Ontario (including Niagara River and International section of the St. Lawrence River)

Status (based on data from 2021 to 2023): Fair

10-Year Trend (2013–2023): Unchanging

Long-term Trend (1995–2023): Improving

Rationale: Annual median IBC in coastal wetlands in Lake Ontario ranged from 1.0 (2003) to 2.7 (2020) from 1995 to 2023, did not significantly improve or deteriorate over the past 10 years (2013–2023) with fairly similar annual values in between, and significantly improved by 1.7% per year (0.5, 2.9) [lower, upper 95% confidence limits for % annual change] over the long term (1995–2023). Median IBC was 2.3 based on data from 2021 to 2023, which is within the defined range for Fair status: 2.0 ≤ median IBC ≤ 3.9.

Status Assessment Definitions

Status and trends are based on the Index of Biotic Condition (IBC), a bird-based index of wetland health (Howe et al., 2023). IBCs range between 0 (Poor condition or most degraded) and 10 (Good condition or least degraded). Status was determined by placing the median IBC of coastal wetlands based on data from recent years (for 2025 reporting, status is based on data from 2021 to 2023) into one of three categories: Poor, Fair, or Good. The cut-points between Poor and Fair and between Fair and Good were approximately based on the 25th and 75th percentiles of IBCs throughout the Great Lakes from 2011 to 2023. Defining the cut-points in this manner captures the current baseline and will therefore be useful for promoting and measuring important, but realistic, improvements in wetland condition over time. Note that the values defining Poor, Fair, and Good below have changed since the 2022 State of the Great Lakes report, as part of the revision of the index used to assess status and trends—see Howe et al. (2023) for details.

Good: median IBC ≥ 4.0, i.e., most wetlands are mildly impacted or in reference condition.

Fair: 2.0 ≤ median IBC ≤ 3.9, i.e., most wetlands are moderately degraded or moderately impacted.

Poor: median IBC ≤ 1.9, i.e., most wetlands are degraded.

Undetermined: Data are not available or are insufficient to assess wetland condition.

Trend Assessment Definitions

Both regional and local marsh bird populations naturally fluctuate over time (Gnass Giese et al., 2018; Timmermans et al., 2008; Tozer et al., 2024). Therefore, several years of monitoring data with suitable geographic coverage are required to detect statistically significant trends. Interpretation of this sub-indicator may be improved if coupled with patterns observed in other wetland sub-indicators (Brazner et al., 2007b, 2007a; Kovalenko et al., 2014).

The terms Improving, Unchanging, and Deteriorating were applied based on geometric mean rates of change in IBCs (% change per year) using equation 4 in Smith et al. (2014):

$$\%\ change\ per\ year = 100 * \left[\left(\frac{IBC_{endYear}}{IBC_{startYear}} \right)^{\frac{1}{endYear - startYear}} - 1 \right]$$

The statistical significance of trends was assessed via parametric bootstrapping in R (R Core Team, 2024) using package "boot" (Canty and Ripley, 2013) and 1,000 bootstrap replicates. Bootstrapping was necessary to account for the varying precision of the annual estimate in the start and end year used to calculate each trend (Tozer, 2016). For 10-year trends, the start year was 2013 and the end year was 2023. The year 2013 was chosen as the start year for 10-year trends because there are 10 possible transitions between years during 2013 to 2023, which was taken to be most representative of the trend during the most recent decade (IUCN Standards and Petitions Committee, 2022). Trend estimates with 95% confidence intervals that did not overlap zero were considered statistically significant.

Improving: A statistically significant increase in IBC.

Unchanging: No statistically significant increase or decrease in IBC, with similar values across years as determined by visual inspection.

No Trend: No statistically significant increase or decrease in IBC, with fluctuations across years as determined by visual inspection; for example, similar start and end values, but increases and decreases in between.

Deteriorating: A statistically significant decrease in IBC.

Undetermined: Data are not available or are insufficient to assess the trend in wetland condition.

Endpoints and/or Targets

Endpoints for this sub-indicator were left undefined for the 2025 report due to uncertainty around the best way to calculate meaningful values. Ongoing work by the authors will strive to develop useful endpoints.

Sub-Indicator Purpose

To assess the status and trends of the ecosystem health of Great Lakes coastal wetlands by directly measuring the composition and occurrence of wetland birds, and thereby inferring the condition of coastal wetland habitat for this ecologically and culturally important component of wetland communities.

Ecosystem Objective

Coastal wetlands provide critical habitat for wildlife such as birds. Conservation of remaining coastal wetlands and restoration or enhancement of previously degraded or destroyed wetlands are vital components of restoring the Great Lakes ecosystem. Birds are effective ecological indicators and can be used to report progress toward such an objective.

This sub-indicator best supports work towards General Objective #5 of the 2012 Great Lakes Water Quality Agreement, which states that the Waters of the Great Lakes should "support healthy and productive wetlands and other habitats to sustain resilient populations of native species."

Methods

Background—Wetland birds are influenced by the physical, chemical, and biological components of wetlands and their surrounding landscapes. For example, the occurrence, abundance, and/or reproductive success of multiple bird species in the Great Lakes basin decline as (1) wetland size decreases; (2) wetland habitat and natural cover in the surrounding landscape decrease or degrade in quality; (3) pollution from pesticides, herbicides, and sediment runoff increases; (4) generalist predators (e.g., northern raccoon [*Procyon lotor*]) associated with anthropogenic habitats in the surrounding landscape increase; and (5) lake levels decrease (Brazner et al., 2007a, 2007b; Crosbie and Chow-Fraser, 1999; Gnass Giese et al., 2018; Grandmaison and Niemi, 2007; Hohman et al., 2021; Howe et al., 2007a; Naugle et al., 2000; Smith and Chow-Fraser, 2010a, 2010b; Timmermans et al., 2008; Tozer et al., 2010, 2020, 2024). Thus, the occurrence or abundance of sensitive wetland birds can be a valuable indicator of the health of wetlands and the surrounding landscape.

Data—Several initiatives monitor Great Lakes wetland birds. One of the longest running is the Great Lakes Marsh Monitoring Program (GLMMP) delivered by Birds Canada, which started in 1995 and has operated every year since then at coastal and inland wetlands throughout much of the Great Lakes basin in the USA and Canada (Tozer, 2020, 2016). Some of the previous reports for this sub-indicator were based solely on data from this ongoing broad scale program (e.g., Tozer, 2014). More recently, the Great Lakes Coastal Wetland Monitoring Program (CWMP) started in 2011 and is currently scheduled to operate until at least 2025 throughout both the U.S. and Canadian Great Lakes coastal zones (Uzarski et al., 2017). The CWMP is a program of the United States Environmental Protection Agency (USEPA) delivered by Central Michigan University and dozens of partner organizations in the U.S. and Canada (greatlakeswetlands.org/Collaborators). These programs have somewhat different study designs but rely on standardized, fixed duration point counts that can be adjusted to maximize cross-project compatibility. To garner large numbers of skilled, trained, volunteer surveyors to achieve large sample sizes at relatively low cost, and to engage the public in the importance of wetlands and wetland conservation, the GLMMP allows participants to select sample wetlands and sample points within them—a justifiable approach if one assumes that the sample locations are representative of wetlands across a region of interest. By contrast, the CWMP selects sample wetlands via stratified random sampling and surveys sample points within them via paid professional staff. Nonetheless, both programs target wetlands dominated by non-woody emergent plants, such as cattails (*Typha* spp.) and sedges (e.g., *Carex* spp.), with sample points located within wetlands. Furthermore, Tozer (2020) showed that, in southern Ontario, annual indices of population abundance for 9 of 10 marsh-breeding bird species were not statistically different in each of three years when based on data collected by GLMMP participants, as compared to data collected by paid professional staff at stratified random locations throughout the same study area. In this report, the GLMMP and CWMP datasets described above were brought together to generate a comprehensive analysis of the status and trend of Great Lakes coastal wetland birds and associated wetland health. We note that only GLMMP data from coastal wetlands

were used for assessments of status or trends in this report, whereas GLMMP data from inland wetlands were analyzed and illustrated only to provide context and for making comparison to results from coastal wetlands. Coastal wetlands were defined as wetlands under direct hydrologic influence from Great Lakes waters or their connecting river systems, whereas inland wetlands were not under direct hydrologic influence (McKee et al., 1992).

Surveys—Wetland birds were sampled to an unlimited distance from one point (hereafter "sample point"), or up to eight sample points, located at the edge of or within a wetland (> 100 m from the edge) depending on its size. In most large wetlands, sample points were placed near the upland/wetland interface (shoreline) and in the interior of the wetland, as well as along the open lake/wetland interface, with sample points distributed as much as possible throughout the wetland in all major vegetation types. In most small wetlands, only shoreline points were sampled. Sample points were > 250 m apart to avoid multiple detections of the same individuals. Depending on the year and program, each sample point was surveyed for 10 or 15 minutes on one to three visits separated by at least 10 or 15 days during the main avian breeding season, typically between late May and early July. Differences among the field protocols have been shown to have minor influence on the probability of detecting most of the species considered in this report (Tozer et al., 2016, 2017a). Surveys occurred in either the morning (30 minutes before local sunrise to 10:00 h local time) or evening (4 hours before local sunset to dark) and only under weather conditions that were favorable for detecting all species and individuals present (little to no precipitation; wind: Beaufort 0–3, 0–19 km/hr). Observers broadcasted calls during surveys to entice vocal response by individuals of especially secretive species. The broadcast calls occurred during a 5-minute portion of each 10- or 15-minute survey and consisted of 30 seconds of vocalizations followed by 30 seconds of silence for each of the following species: Least Bittern (*Ixobrychus exilis*), Sora (*Porzana carolina*), Virginia Rail (*Rallus limicola*), a mixture of American Coot (*Fulica americana*) and Common Gallinule (*Gallinula galeata*), and Pied-billed Grebe (*Podilymbus podiceps*), in that order. The survey protocols of each of the programs closely follow the Standardized North American Marsh Bird Monitoring Program protocol (Conway, 2011). The survey protocols are summarized in Tozer (2016) for the GLMMP, and in Uzarski et al. (2017) for the CWMP.

Analysis

Background—Numerous methods are available for assessing the health of Great Lakes coastal wetlands based on bird data. Some previous analyses for this report were based on the separate status and trends of the relative abundance of approximately 20 wetland bird species (e.g., Tozer, 2014). Alternative approaches include various bird-based indices of wetland health, which combine data from suites of species (Chin et al., 2015). The latter approach is likely more objective and more practical for the purposes of State of the Great Lakes reporting because it provides a single comprehensive metric that represents the collective responses of bird species to wetland condition. Multi-species metrics, like the widely used index of biotic integrity for fishes (Karr and Chu, 1999) and mean coefficient of conservatism for plants (Taft et al., 1997), are robust when they are tested against known stressor gradients and include enough species to allow for calculations even if some species are absent due to extraneous factors. For example, a wide-ranging resident species might go undetected because, by chance, all local individuals of that species happen to be absent or inactive within the survey plot during the sampling period. Similarly, a high-quality wetland might be missing a species because of factors unrelated to habitat, such as a regional epidemic that affects individuals regardless of wetland condition or bird declines caused by mortality during migration. Since 2017, analyses for this report have been based on multi-species indices first developed by Howe et al. (2007a, 2007b) and refined in Tozer et al. (2017b, 2019, 2022). In this report, we assess coastal wetland bird status and trends based on the multi-species metric described by Howe et al. (2023), referred to as the Index of Biotic Condition (IBC), which builds on the strengths of the previous multi-species metrics used in this report (see Howe et al., 2023 for details).

Species—We restricted our analysis to species that are obligate marsh nesters or frequent users of marsh habitat for feeding (Table 1). We excluded species associated with peripheral habitats, such as woodlands and shrub wetlands (e.g., Alder Flycatcher, *Empidonax alnorum*; Willow Flycatcher, *Empidonax traillii*; Yellow Warbler, *Setophaga petechia*; and Song Sparrow, *Melospiza melodia*). Aerial foragers (e.g., swallows and swifts) were excluded because their feeding sites often include open lakes, fields, and other non-wetland habitats. Bald Eagle (*Haliaeetus leucocephalus*) and Osprey (*Pandion haliaetus*) use non-wetland habitats for breeding, but they were included in our analysis because they capture prey (fish) directly from wetlands and were identified as species that are sensitive to our quantitative "human footprint" gradient (see below). We excluded species that were recorded in fewer than 5% of the point samples because responses to human-induced stress are statistically very weak for species that are rarely encountered. Uncommon or rare species are important for conservation and ecological restoration, so we created several combinations of ecologically-related species to account for seldom-encountered or geographically-limited wetland-obligate bird species (Table 1). For example, we combined several species of shallow-water "dabbling" ducks into a single category: American Black Duck (*Anas rubripes*), Green-winged Teal (*A. carolinensis*), Northern Pintail (*A. acuta*), American Wigeon (*Mareca americana*), Gadwall (*M. strepera*), Blue-winged Teal (*Spatula discors*), Northern Shoveler (*S. clypeata*), and Wood Duck (*Aix sponsa*). We excluded Mallard (*Anas platyrhynchos*), as this species is often abundant in highly-impacted, urban/suburban environments. These dabbling duck species all feed on aquatic plants, seeds, and small animal prey in shallow water. Multi-species groups (see Table 1) are generally comprised of ecologically-similar bird species. One exception is the "Other" category, which includes three uncommon species that are linked because they are primarily found in high-quality, shallow wetlands in the Great Lakes: Northern Harrier (*Circus hudsonius*), Wilson's Phalarope (*Phalaropus tricolor*), and Wilson's Snipe (*Gallinago delicata*). Some groupings were established to account for biogeographic differences in distribution. For example, Sedge Wren (*Cistothorus stellaris*) is more frequent in wet meadows of northern Great Lakes wetlands, while Marsh Wren (*Cistothorus palustris*) is more frequent in cattail-dominated wetlands of southern Great Lakes, even though both species' ranges cover the entire Great Lakes. Despite their different habitat preferences, based on results from biotic response functions (details below), these two small, foliage-gleaning insectivores responded similarly to the environmental gradient (although Sedge Wren was somewhat more sensitive) and therefore they were combined to reduce biogeographic bias caused by their uneven geographic distributions. Likewise, two species that prey on frogs, crustaceans, insects, and small fish along wetland edges, American Bittern (*Botaurus lentiginosus*; more frequent in northern and western Great Lakes coastal wetlands) and Least Bittern (more frequent in southern and eastern wetlands), were combined to account for their somewhat complementary distribution patterns. In general, the 14 bird taxa (Table 1) selected for our analysis can potentially occur anywhere in the Great Lakes coastal zone where their ecological needs are met.

Environmental reference gradient—The first step in calculating the IBC is to quantify the responses of the selected taxa to an explicit, independently-derived gradient of environmental condition (Howe et al., 2007b). The nature of this gradient is critical to the estimation of species- or taxon-specific responses to the gradient. Our purpose was to identify species or species groups that are sensitive to environmental stress and to characterize the nature of these responses over a reference gradient of increasing environmental quality (or inverse environmental stress). Because the IBC is used for assessing conservation priorities and for monitoring the outcome of conservation actions, we attempted to represent a wide range of environmental stressors that can be mitigated by conservation actions. Coastal wetlands can be degraded by a host of factors, including direct habitat destruction or fragmentation, cultural eutrophication, invasive species, industrial or agricultural toxins, hydrological disturbances, and long-term changes in physical conditions (e.g., water levels, precipitation amounts, air and water temperature) (Allan et al., 2013; Danz et al., 2007). To capture the diversity of these many different factors, we refer to the environmental reference gradient as the "human footprint" (Gnass Giese et al., 2015; Venter et al., 2016).

We used a combination of landscape and local variables to quantify potential environmental stress among 580 coastal wetlands for which relevant land cover data were available. Elliott (2019) developed multi-scale occupancy models for selected cryptic marsh birds using more than 50 habitat, landscape, hydrologic, and atmospheric variables associated with wetlands in the Great Lakes region. We selected six of these variables for estimating potential environmental stress: 1) percent cover of developed land (industrial buildings, residential sites, golf courses, etc.) within 2 km of the sample point; 2) percent cover of agricultural cropland within 2 km of the sample point; 3) total meters of primary and secondary roads within 2 km of the sample point; 4) percent cover of non-woody emergent wetland within 500 m of the sample point, 5) percent cover of cropland in the entire watershed associated with the wetland, and 6) percent cover of developed land within the watershed. The latter two variables were calculated by Brazner et al. (2007b) and Danz et al. (2007b). These six environmental variables were selected because they are minimally correlated ($-0.30 \leq r \leq 0.31$) and represent three scales of reference: local (< 500 m), landscape (< 2 km), and watershed. Notably, the two agricultural land cover variables ($r = -0.01$) and the two land development variables ($r = 0.02$) were largely independent.

We relativized each of the six variables to a uniform scale (0–10), with percent cover of non-woody emergent wetland reversed, so that in all cases 0 = worst condition and 10 = best condition. We did this for each variable by designating the highest value as 10, and then standardized all other values to the observed range as follows:

$$Relativezed\ score = \left[\frac{V_x}{(V_{max} - V_{min})}\right] * 10$$

Where V_x = the measured value for wetland x.

The average score among the six adjusted variables therefore yielded an overall environmental condition index (Cenv) also ranging from 0 to 10. The collection of all Cenv scores among wetland sampling points defined a reference gradient for analysis of each bird species' sensitivity (or biotic response) to the "human footprint."

Biotic response (BR) functions—Howe et al. (2007b) used an asymptotic function to calculate taxon-specific responses to the environmental reference gradient. More recent applications (e.g., Gnass Giese et al., 2015) have applied a general normal probability distribution function, yielding some part of the familiar bell-shaped curve. Both of these functions aim to accurately quantify how species or groups of species respond to changes in environmental condition. By specifying the range of relevant values (0–10), but allowing the function's mean to lie within or outside this range, we can generate best-fit "curves" that are monotonically increasing (the upward part of the normal curve), monotonically decreasing (the downward part of the normal curve), or unimodal with complete or truncated tail(s). We have written an algorithm that selects the best-fit parameters of the normal bell-shaped curve, following the familiar normal probability density function, using R function *dnorm* (R Core Team, 2024). Three parameters define the curves: μ = mean; σ = standard deviation; and h = scale factor. The best-fit parameters are estimated by an R script with the *nlminb* function developed by Bates and Sarkar (Gray, 1990). We used the sum of squared deviations of data points from the predicted normal distribution as the goodness-of-fit criterion.

The land use variables used by Elliott (2019) were derived from the 2010 North American Land Cover 30-m dataset from the North American Land Change Monitoring System. Great Lakes water levels reached record-lows during the late-1990s to early-2010s and then increased to unprecedented highs by 2017 to 2020 depending on the lake, which caused significant changes in the coastal zone (Gronewold and Rood, 2019). To minimize the mismatches between land cover variables and coastal wetland bird occurrences, we only used bird point samples from 2011 to 2015 (n = 1,557) for generating BR functions. The parameters from this analysis can be applied to wetland assessments in any year; our purpose in generating the BR functions was simply to quantify the relative sensitivity of different species or species groups to an empirical gradient of wetland disturbance.

Groups of 10 bird sampling points with the most similar environmental condition scores (Cenv) were combined into "bins" for calculating probabilities of occurrence across the reference gradient. For example, points with the 10 lowest Cenv scores were assigned to the first bin, points with the next 10 lowest scores were assigned to the second bin, and so on. The last bin contained only 7 points, since our 1,557 samples were not evenly divisible by 10. Sometimes bins included multiple points from the same wetland, but typically they included points from different lakes or distant parts of the same lake. A species' probability of occurrence (i.e., frequency) in each bin is defined as the proportion of the 10 points where the species was detected during at least one of the two point-specific counts during a sample year. The environmental condition score for each bin was the mean value of scores (mean of the six relativized environmental variables) for the 10 points.

BR functions for the 14 taxa (Figure 1) provide information about the relative frequency/probability of occurrence of each species in Great Lakes coastal wetlands (the height of the curve) and the sensitivity of the species to differences in Cenv (i.e., the shape of the curve across the 0–10 environmental gradient). These curves best describe the reality of how frequent (or infrequent) a species is in this system and how these frequencies change across the gradient. Birds like bitterns, Sandhill Crane (*Antigone canadensis*), grebes, and terns show strong sensitivity to the gradient (i.e., they are most frequent at sites with high Cenv), but they are generally uncommon, rarely achieving a probability of 0.5 or greater in any of the 156 bins. Common Yellowthroat (*Geothlypis trichas*) and Red-winged Blackbird (*Agelaius phoeniceus*), on the other hand, are found in almost every wetland, including wetlands strongly impacted by human activities.

Index of Biotic Condition (IBC)—IBC values for individual points are calculated using parameters from BR functions for ecologically-relevant taxa (Table 1) encountered during standardized field surveys. Weights for each species or species group were calculated as the product of two parameters: 1) the mean of the BR function, $\bar{x}_i$ (the value of Cenv when the BR function is at its peak frequency or probability of occurrence), and 2) the difference between $p(\bar{x}_i)_i$ (the predicted probability of occurrence of the species/species group at the mean of the BR function) and $p(0)_i$ (the predicted value of the BR function when the environmental gradient (Cenv) = 0). The BR function mean, $\bar{x}_i$, reflects the sensitivity of the species to the reference gradient; in general, the more sensitive the species, the larger the mean. The shape of BR functions can represent normal distribution functions whose means extend beyond the limits (0–10) of the reference gradient (Gnass Giese et al., 2015), but we capped the maximum value of $\bar{x}_i$ for calculating weights at 15. The second parameter $[p(\bar{x}_i)_i - p(0)_i]$ reflects the difference between the peak frequency of occurrence/detection of the species and its frequency of occurrence/detection when the environmental condition is most degraded (Cenv = 0). If two species are equally infrequent at degraded sites, absence of the more common species will impose a larger penalty on the IBC score because the common species is more frequent at peak conditions. Absence of rare species generally carries a relatively small penalty because these species never reach a high frequency.

The value of IBC is the sum of weights for all species present at the wetland during the two seasonal point counts, scaled from 0 (when no species are present) to 10 (when all species are present):

$$IBC = \left[\sum_{i=1}^{present} \bar{x}_i \left[p(\bar{x}_i)_i - p(0)_i\right]\right]\left[10 / \sum_{j=1}^{all} w_j\right]$$

where:

$\bar{x}_i$ = mean of the BR function for species i,

$p(\bar{x}_i)_i$ = predicted probability of the species/species group occurring at the peak of the BR function; i.e., when Cenv = $\bar{x}_i$,

$p(0)_i$ = predicted probability of the species/species group occurring when Cenv = 0, and

$\sum_{j=1}^{all} w_j$ = sum of weights of all species used in the analysis, even those absent in the sample (in our case, the sum of the weights of 14 species or species groups, or 24.19; Table 1).

Because we have derived empirical species weights from BR functions of sampled Great Lakes bird assemblages between 2011 and 2015 (Table 1), the IBC calculation for Great Lakes coastal wetland birds can be simplified to:

$$IBC = \left[\sum_{i=1}^{present} w_i\right] 0.414$$

where:

w_i = predetermined weight for species i (Table 1).

In other words, the IBC is simply the sum of weights for all taxa present multiplied by the scaling factor 0.414, which adjusts the IBC values to range from 0 (worst condition) to 10 (best condition). Note that the scaling factor will be different for other systems or groups of species.

IBCs for each sample point during a given year were based on species detected during any one of the field visits. Next, the point-level IBCs were averaged across all sample points within each wetland or wetland complex in each year, which standardizes wetlands containing differing numbers of sample points. Box-and-whisker plots of these wetland-level mean IBCs for coastal wetlands in each basin and throughout the entire Great Lakes basin (hereafter "overall") are reported in each year. These wetland-level means form the basis for the status and trend assessments. IBC metrics were also calculated for inland wetlands for comparison to Great Lakes coastal wetlands, but are not used for any assessments of status or trends. In addition, box-and-whisker plots of wetland-level mean IBCs for coastal wetlands in each basin and overall based on data in recent years (2021–2023) are reported to illustrate current status. Density plots of wetland-level mean IBCs for coastal and inland wetlands in each basin (but not inland for Lake Superior due to insufficient sample size) based on the most recent 5 years of data (2019–2023) are reported to illustrate variation in distributions. These plots can be thought of as smoothed histograms, which are useful for continuous data that come from an underlying smooth distribution. To further illustrate distributions, these same data for coastal wetlands are mapped throughout each of the basins. In the calculations for status, density plots, and the map, wetland-level mean IBC values were averaged across years for wetlands that were sampled in multiple years. We used the most recent 3 years of data (2021–2023) for status calculations because these data were newly-available since the previous report, and we used the most recent 5 years of data (2019–2023) for density plots and the map to maximize the total number of wetlands depicted, given nearly all of the wetlands were surveyed in at least one of the past 5 years.

Discussion

Data coverage—The dataset consisted of 49,568 point counts conducted at 5,952 sample points in 1,908 wetlands over 29 years from 1995 to 2023 throughout coastal and inland areas of the Great Lakes basin (Figure 2). The number of years that each wetland was surveyed varied from 1 to 28, with a mean of 4.4 years ± 4.6 (SD), due mostly to large differences in observer participation in the long-running, broad-scale GLMMP (Figure 2). The majority of the surveyed wetlands were coastal (*n* = 1,283; 67%) rather than inland (*n* = 625; 33%) because the CWMP focused entirely on coastal wetlands, whereas the GLMMP surveyed both coastal and inland wetlands (Figure 2).

The number of coastal and inland wetlands surveyed per year (287 ± 138 [mean ± SD]) ranged from 110 to 490, with substantially more wetlands surveyed from 2011 to 2023 due to the CWMP operating during those years (Figure 3). Annual coverage was higher in Lake Erie and Lake Ontario compared to the upper Great Lakes mostly because GLMMP coverage is more extensive in the lower lakes. Annual coverage was higher at coastal compared

to inland wetlands (Figure 3). The number of wetlands available for surveys also varied depending on location, as some sections of the Great Lakes shoreline naturally have no, or almost no, wetlands. As a result of low sample sizes in certain years (Figure 3), we focus on data from coastal wetlands from 2011 to 2023 for lakes Superior, Michigan, and Huron, and in the Great Lakes overall, and data from 1995 to 2023 for lakes Erie and Ontario.

Overall—Annual median IBC in coastal wetlands in the Great Lakes overall ranged from 1.9 (2012) to 2.8 (2020) out of 10 from 2011 to 2023, and did not significantly improve or deteriorate over the past 10 years (2013–2023) despite some annual increases and decreases in between (Table 2, Figure 4). Median IBC was 2.3 based on data from 2021 to 2023 (Figure 5). For this report, we concluded that there was not enough information to perform reliable statistical significance testing for long-term trends due to low sample size in lakes Superior, Michigan, and Huron during 1995 to 2010 (Figure 3). We note that even though the recent 10-year trend (2013–2023) was not significant, there was a consistent increase in median IBC in coastal wetlands from 2011 until 2020, followed by a decrease in the most recent few years (Figure 4). Based on these patterns, the status of coastal wetland health based on bird communities in the Great Lakes overall is Fair, and the trend assessment is No Trend. IBCs at inland wetlands in the Great Lakes watershed showed little change across years, and were similar compared to coastal wetlands based on data from 2021 to 2023 (median inland IBC based on data from 2021 to 2023 = 2.0; Table 2; Figures 4, 7). A mix of low (< 4) and high (> 6) IBCs occurred throughout each of the lakes, except Lake Superior where IBCs were lower in general (Figure 6). Notable clusters of high IBCs occurred in the St. Marys River channel, eastern Lake St. Clair, and Long Point, Lake Erie (Figure 6).

Since the 2022 State of the Great Lakes report, the 10-year trend for coastal wetlands in the Great Lakes overall has changed from Improving to No Trend, and the long-term trend has changed from Unchanging to Undetermined. The difference in the 10-year trend may be due to improvements in assessment methodology since the last report (Howe et al., 2023), and/or changes in lake levels, which drive changes in wetland bird habitat and associated IBCs (see Analysis and Comments for details). The difference in the long-term trend is due to the determination that sample sizes were too limiting in lakes Superior, Michigan, and Huron during 1995 to 2010 for an overall assessment (Figure 3).

Lake Superior—Annual median IBC in coastal wetlands ranged from 1.4 (2019) to 2.3 (2021) out of 10 from 2011 to 2023, and did not significantly improve or deteriorate over the past 10 years (2013–2023) despite some annual increases and decreases in between (Table 2, Figure 4). Median IBC was 2.0 based on data from 2021 to 2023 (Figure 5). For this report, we concluded that there was not enough information to perform reliable statistical significance testing for long-term trends due to low sample size during 1995 to 2010. We note that even though the recent 10-year trend (2013–2023) was not significant, there was an increase in median IBC in coastal wetlands from 2011 until 2022, followed by a decrease in 2023, a pattern also noted to varying degrees in lakes Michigan, Huron, and Erie (Figure 4). Based on these patterns, the status of coastal wetland health based on bird communities in Lake Superior is Fair, and the trend assessment is No Trend. IBCs at inland wetlands in the Lake Superior watershed were too sparse for meaningful comparison with coastal wetlands (Figure 3, 4). The coastal landscape adjacent to Lake Superior is generally non-agricultural and minimally-developed, and the lake's coastal wetlands are less stressed by anthropogenic activities compared to wetlands in the more southern lakes (Allan et al., 2013; Bourgeau-Chavez et al., 2015). However, coastal wetlands of Lake Superior are small in area, tend to have lower productivity, and are ecologically quite different compared to the rest of the lakes, which likely accounts at least partially for the lower IBCs in Lake Superior compared to the other lakes (Figures 4–7). The northern character of Lake Superior's wetlands may offer less plant and insect food for many wetland birds compared to more southern lakes due to fewer nutrients as a function of hard, underlying, granitic bedrock and much lower anthropogenic inputs (Environment Canada, 2002; Hanowski et al., 2007).

Since the 2022 State of the Great Lakes report, the 10-year trend for coastal wetlands in Lake Superior has changed from Undetermined to No Trend. The difference is due to substantially more coastal wetlands being surveyed from 2011 to 2023 by the CWMP, which provided suitable sample sizes during the past 10 years for statistical analysis.

Lake Michigan—Annual median IBC in coastal wetlands ranged from 1.1 (2014) to 3.1 (2020) out of 10 from 2011 to 2023, and did not significantly improve or deteriorate over the past 10 years (2013–2023) despite some annual increases and decreases in between (Table 2, Figure 4). Median IBC was 2.4 based on data from 2021 to 2023 (Figure 5). For this report, we concluded that there was not enough information to perform reliable statistical significance testing for long-term trends due to low sample size during 1995 to 2010. We note that even though the recent 10-year trend (2013–2023) was not significant, there was an increase in median IBC in coastal wetlands from the early-2010s until 2020, followed by a decrease in the most recent few years, a pattern also noted to varying degrees in lakes Superior, Huron, and Erie (Figure 4). Based on these patterns, the status of coastal wetland health based on bird communities in Lake Michigan is Fair, and the trend assessment is No Trend. IBCs at inland wetlands in the Lake Michigan watershed were too sparse for meaningful comparison with coastal wetlands (Figure 4).

Since the 2022 State of the Great Lakes report, the 10-year trend for coastal wetlands in Lake Michigan has changed from Undetermined to No Trend. The difference is due to substantially more coastal wetlands being surveyed from 2011 to 2023 by the CWMP, which provided suitable sample sizes during the past 10 years for statistical analysis.

Lake Huron (including St. Marys River)—Annual median IBC in coastal wetlands ranged from 2.0 (2012) to 3.0 (2018) out of 10 from 2011 to 2023, and did not significantly improve or deteriorate over the past 10 years (2013–2023) despite some annual increases and decreases in between (Table 2, Figure 4). Median IBC was 2.3 based on data from 2021 to 2023 (Figure 5). For this report, we concluded that there was not enough information to perform reliable statistical significance testing for long-term trends in coastal wetlands due to low sample size during 1995 to 2010. We note that even though the recent 10-year trend (2013–2023) was not significant, there was a consistent increase in median IBC in coastal wetlands from the early-2010s until 2019, followed by a decrease in the most recent few years, a pattern also noted to varying degrees in lakes Superior, Michigan, and Erie (Figure 4). Based on these patterns, the status of coastal wetland health based on bird communities in Lake Huron is Fair, and the trend assessment is No Trend. IBCs at inland wetlands showed little change across years, were consistently higher during 2016 to 2023 compared to earlier years, and were similar compared to coastal wetlands based on data from 2021 to 2023 (median inland IBC based on data from 2021 to 2023 = 2.3; Table 2; Figures 4, 7). The elevated IBCs at inland wetlands during 2016 to 2023 were likely due to improved sampling design for the GLMMP during that time.

Since the 2022 State of the Great Lakes report, the status of coastal wetlands in Lake Huron has changed from Good to Fair, and the 10-year trend has changed from Unchanging to No Trend. The difference in status may be due to improvements in assessment methodology since the last report, and/or changes in lake levels, which drive changes in wetland bird habitat and associated IBCs (see Analysis and Comments for details). The difference in trend is due to the adoption of a new term “No Trend” to better describe the pattern of annual fluctuations within the time period of the trend (see Trend Assessments Definitions above for details).

Lake Erie (including St. Clair-Detroit River Ecosystem)—Annual median IBC in coastal wetlands ranged from 1.6 (2001) to 3.5 (2009) from 1995 to 2023, and did not significantly improve or deteriorate over the past 10 years (2013–2023) or over the long term (1995–2023) despite some annual increases and decreases in between (Table 2, Figure 4). Median IBC was 2.3 based on data from 2021 to 2023 (Figure 5). We note that even though the recent 10-year trend (2013–2023) was not significant, the median IBC was lower in coastal wetlands from the early-

2010s to 2019, was highest in 2020, followed by a decrease in the most recent few years, a pattern also noted to varying degrees in lakes Superior, Michigan, and Huron (Figure 4). Based on these patterns, the status of coastal wetland health based on bird communities in Lake Erie is Fair, and the trend assessment is No Trend. IBCs at inland wetlands showed little change across years, were consistently higher during 2011 to 2023 compared to earlier years, and were lower compared to coastal wetlands based on data from 2023 (median inland IBC based on data from 2021 to 2023 = 1.7; Table 2; Figures 4, 7). It is unclear what might have caused the elevated IBCs at inland wetlands during 2011 to 2023 compared to earlier years.

Since the 2022 State of the Great Lakes report, the 10-year trend and the long-term trend for coastal wetlands in Lake Erie has changed from Unchanging to No Trend. The difference is due to the adoption of a new term "No Trend" to better describe the pattern of annual fluctuations within the time period of the trend (see Trend Assessments Definitions above for details).

Lake Ontario (including Niagara River and International section of the St. Lawrence River)—Annual median IBC in coastal wetlands ranged from 1.0 (2003) to 2.7 (2020) from 1995 to 2023, did not significantly improve or deteriorate over the past 10 years (2013–2023) with fairly similar annual values in between, and significantly improved by 1.7% per year (0.5, 2.9) [lower, upper 95% confidence limits for % annual change] over the long term (1995–2023; Table 2, Figure 4). Median IBC was 2.3 based on data from 2021 to 2023 (Figure 5). Based on these patterns, the status of coastal wetland health based on bird communities in Lake Ontario is Fair, and the trend assessment is Unchanging. IBCs at inland wetlands in the Lake Ontario watershed showed little change across years, and were slightly lower compared to coastal wetlands based on data from 2023 (median inland IBC based on data from 2021 to 2023 = 1.9; Table 2; Figures 4, 7).

Since the 2022 State of the Great Lakes report, the 10-year trend for coastal wetlands in Lake Ontario has changed from Improving to Unchanging. The difference may be due to improvements in assessment methodology since the last report (see Analysis for details).

Comments—The status of wetland birds as a measure of coastal wetland health throughout the Great Lakes was Fair based on data from the most recent 3 years (2021–2023). The status based on the most recent 3 years (2021–2023) was also Fair in lakes Superior, Michigan, Huron, Erie, and Ontario (note that a separate determination of status and trend was made for the Overall Assessment based on data from all of the individual lake basins, rather than averaging across the lake-by-lake assessments). Despite the Fair status throughout the Great Lakes, it is important to note that high-quality coastal wetlands (IBC ≥ 6) are present throughout each of the Great Lakes, except Lake Superior due to its unique northern ecological character (Figure 4–7). By illustrating and documenting differences in wetland health based on wetland bird communities, we provide a unique baseline that informs wetland restoration and conservation efforts at various scales across the Great Lakes basin. For instance, the presence of high-quality wetlands with healthy wetland bird communities (IBC ≥ 6) in highly stressed regions of the Great Lakes, such as Green Bay in Lake Michigan, Saginaw Bay in Lake Huron, and eastern Lake St. Clair, among others (Figure 6), is highly encouraging and supports investment in wetland restoration and conservation efforts targeting wetland birds and associated wetland health throughout the Great Lakes.

The trend assessment for coastal wetland birds as a measure of wetland health was No Trend throughout the Great Lakes basin over the past decade (2013–2023). Even though the recent 10-year trend (2013–2023) was not significant, there was a consistent increase in annual median IBC in coastal wetlands throughout the Great Lakes basin from 2011 until 2020, followed by a decrease in the most recent few years (Figure 4). The same pattern occurred to varying degrees in coastal wetlands in the individual basins of lakes Superior, Michigan, Huron, and Erie, but not Ontario (Figure 4). The pattern is very likely due to concurrent changes in lake levels, as suggested by the absence of the pattern in Lake Ontario where regulated water levels fluctuate much less compared to the other lakes (Figure 4; Denomme-Brown et al., 2023). In general, water levels in the Great Lakes (excluding Lake Ontario)

declined and reached record lows during the mid-1990s to early-2010s (e.g., mean decrease in lake level from 1995 to 2002: 0.06–0.41 m depending on the lake; Timmermans et al., 2008), then rose and reached record highs during the early-2010s to early-2020s (e.g., mean increase in lake level from 2013 to 2018: 0.16–0.97 m depending on the lake; Hohman et al., 2021), and then began to decline again thereafter (see Water Levels Sub-Indicator for further details including historical context back to 1918; Gronewold et al., 2021; Lam and Dokoska, 2022; Mayne et al., 2022). This pattern is also evident in trends of annual abundance indices of multiple wetland bird species that are used to calculate the IBC (e.g., bitterns, rails; see Tozer et al. 2024 for a detailed analysis). It appears, therefore, that the overall health and ecological condition of Great Lakes coastal wetlands based on wetland birds is driven at least partially by low (generally Poor condition) and high (generally Good condition) lake levels, although there is considerable variation in this generality across individual wetlands and Great Lakes.

Increasing lake levels likely increased habitat quality for many of the wetland bird species by inundating marsh vegetation, given many of the species prefer water depths of > 20–30 cm (Desgranges et al., 2006; Lor and Malecki, 2006; Tozer et al., 2010). Habitat quality was likely also improved by increasing water levels due to associated increases in open water-vegetation interspersion (i.e., the amount of emergent vegetation edge) and extent of open water (Rehm and Baldassarre, 2007). This is partly because availability of prey, such as invertebrates and fish, is influenced by emergent vegetation edges (Voigts, 1976) and the availability of submerged vegetation for herbivorous species is influenced by the extent of open water (Brackney and Bookhout, 1982). Some of the species included in the IBC have been found to increase by several hundred percent in response to increasing interspersion and open water extent (Bolenbaugh et al., 2011; Dinehart et al., 2023; Rehm and Baldassarre, 2007; Steen et al., 2006; Wyman and Cuthbert, 2017), and interspersion increased by 20% and open water extent by 43% in coastal wetlands throughout the Great Lakes between a low-water year (2013) and a high-water year (2018; Hohman et al., 2021). Therefore, the increase in median IBCs from the early-2010s to 2020 was likely caused by increasing lake levels, which increased habitat quality for many wetland bird species, not only by inundating marsh vegetation, but also by increasing the interspersion of, and open water extent within, marsh vegetation. It follows that the decrease in median IBCs after 2020 over the most recent few years was likely caused by decreasing lake levels, which decreased habitat quality for many wetland bird species due to associated decreases in inundation, interspersion, and open water extent.

The association between Great Lakes water levels, coastal wetland bird communities, and associated wetland health potentially has large implications for conservation of Great Lakes coastal wetlands. By contrast, median IBCs based on wetland birds at inland wetlands in the Great Lakes basin showed different patterns over time compared to coastal wetlands, and unsurprisingly appeared to be uninfluenced by Great Lakes water levels (Figure 4). This suggests that high-lake-level-induced increases in wetland birds in Great Lakes coastal wetlands may be important for boosting regional populations. Coastal wetland protection and restoration are of utmost importance to safeguard this process. More information on how observed increases in wetland birds in coastal wetlands may translate into regional population increases across the Great Lakes basin would be useful for conservation planning. For instance, if wetland bird abundance remains high enough for long enough in coastal wetlands do individuals eventually “spill over” (i.e., disperse) to inland wetlands causing an even larger boost to the total population in the Great Lakes region? Continued, standardized monitoring at coastal and inland wetlands by the CWMP and GLMMP will be useful for gauging these patterns at broad scales. The value that Great Lakes coastal wetlands provide as critical reservoirs of high-quality wetland bird habitat will be challenged in the future due to changes in physical and environmental conditions. Future projections for the Great Lakes show potential for large increases in lake levels over the next several decades, including more frequent extremes, i.e., higher highs and lower lows (see Water Levels Sub-Indicator for further details; Kayastha et al., 2022; Lam and Dokoska, 2022; Mayne et al., 2022). This may cause “coastal squeeze” of wetlands (Pontee, 2013) if wetlands are unable to migrate landward fast enough to keep pace with increasing lake levels (Anderson et al., 2023; Hartsock et al.,

2022; Rutherford et al., 2022; Smith et al., 2021). As a result, there will be less coastal wetland bird habitat available to support periodic pulses in wetland bird abundance, which could have negative consequences for regional population dynamics. Actions that remove or prevent barriers to landward movement of wetlands, such as shoreline armoring, riprap, retaining walls, road infrastructure, or other obstructions, help mitigate the negative influence of future high-water extremes on coastal wetland bird habitat (Mayne et al., 2022). For instance, creating upslope "refugia" in key areas would allow coastal wetlands to migrate as water levels rise (Mayne et al., 2022). Likewise, actions that facilitate lakeward movement and persistence of coastal wetlands during low lake level extremes will also help wetland birds resist the effects of water level fluctuations (Snell et al., 2006).

The increase in coastal IBCs from the mid-2010s to 2020 (Figure 4) may also be at least partially due to improvement in coastal wetland condition. An index of water quality significantly improved across 22 wetlands along the Canadian shore of Lake Ontario between 2003 and 2014 (Croft-White et al., 2017). The improvement in water quality is indicative of concurrent improvement in wetland bird habitat (Grabas et al., 2012; Grabas and Rokitnicki-Wojcik, 2015; Tozer, 2016) and might be reflected in the increasing coastal wetland bird IBCs observed in Lake Ontario over the long term (1995–2023; Table 2, Figure 4). Increases in water quality and concurrent improvements in wetland bird habitat associated with restoration efforts may at least partially explain increasing patterns in IBCs elsewhere within the Great Lakes basin.

In addition to assessing status and trend of the health of coastal wetlands, status and trend of inland wetlands were examined for comparison (Table 2; Figures 4, 7). Due to differences in sample sizes, the ability to compare coastal and inland wetlands was best for Lake Erie and Lake Ontario, whereas it was more limited for the other lake basins. It is worth noting that patterns in IBCs differed in some cases between coastal and inland wetlands. In general, where and when IBCs in coastal wetlands increased or decreased, there were no corresponding changes in IBCs at inland wetlands (Table 2, Figure 4). In addition, IBCs at inland wetlands tended to be lower than IBCs at coastal wetlands within any particular lake basin, although this was not always the case (Figure 4). Thus, wetland health as represented by wetland birds may be responding to different intensities of stressors in coastal versus inland wetlands within certain watersheds. This idea is supported by previous analyses using only the GLMMP dataset, which showed that mean abundance of certain wetland-dependent bird species was different at coastal wetlands compared to inland wetlands (Studholme et al., 2023; Tozer, 2020). Thus, continued sampling of both coastal and inland wetlands by the GLMMP, CWMP, and others throughout the Great Lakes basin will be useful for generating a more complete understanding of the health of wetlands based on birds throughout the entire Great Lakes watershed.

The overall Fair status and trend assessment of No Trend reported for coastal wetlands throughout the Great Lakes overall contrasts with some previous reports for this sub-indicator (i.e., before 2019). The differences among the reports are at least partially due to differences in sampling. Some of the previous reports were based predominantly on data from the southern portion of the Great Lakes basin due to reliance on the mostly southern GLMMP dataset (Tozer, 2014). The current report provides a more balanced assessment throughout the entire Great Lakes basin by bringing GLMMP data together with data from the CWMP. Nevertheless, the patterns reported here are based on a comprehensive IBC metric, which represents the collective responses of many wetland bird species to wetland condition. Multiple different species, however, experience long-term population trajectories in the Great Lakes that differ from trends in the IBC (Bianchini and Tozer, 2023; Tozer, 2020, 2016; Tozer et al., 2024). These taxa are likely responding to environmental stressors in species-specific ways, warranting unique actions or presenting unique opportunities for restoration to improve wetland health.

Linkages

Coastal wetland birds are influenced by numerous local and landscape-level characteristics, some of which are monitored by other State of the Great Lakes indicators. For instance, coastal wetland birds are known to be influenced by changing water levels at local and individual Great Lakes basin scales (Gnass Giese et al., 2018; Hohman et al., 2021; Jobin et al., 2009; Timmermans et al., 2008; Tozer et al., 2024). Thus, the Coastal Wetland Birds sub-indicator can be expected to co-vary with the Water Levels sub-indicator (e.g., Chin et al., 2014; see Comments for details), and in turn, with atmospheric-related impacts that indirectly affect water levels, such as the Surface Water Temperatures, Ice Cover, and Precipitation Amounts sub-indicators. As well, the Coastal Wetland Birds sub-indicator can be expected to co-vary with sub-indicators that track the extent and spatial arrangement of wetland bird habitat (e.g., Coastal Wetlands: Extent and Composition, Aquatic Habitat Connectivity) and prey (Coastal Wetland Invertebrate; Coastal Wetland Fish). It can also be expected to co-vary with invasive plant species (e.g., *Phragmites australis*) that encroach upon preferred native vegetation (e.g., Aquatic and Terrestrial Non-Native Species) and pollution that may reduce prey abundance and/or availability (e.g., all of the Toxic Chemicals and Nutrients and Algae indicators). Finally, it can be expected to be influenced by long-term environmental changes , such as through direct mortality of certain coastal wetland bird species as a result of temperature-related outbreaks of type-E botulism (Princé et al., 2018) and through indirect changes in water levels that in turn influence wetland bird habitat (citations above). The Coastal Wetland Birds sub-indicator can be expected to co-vary with the *Cladophora* sub-indicator (rotting mats of algae enhanced by temperature-related factors are known to starting points for botulism; Chun et al., 2015), the Dreissenid Mussels sub-indicator (beds of these mussels enhanced by temperature-related factors are also known to be starting points for botulism; Getchell and Bowser, 2006), and with all of the Changes in Physical Conditions indicators (including Water Levels, Surface Water Temperature, Ice Cover, and Amount of Precipitation).

Citizen Science, Traditional Ecological Knowledge (TEK), and other Bodies of Knowledge

The tremendous power to report robust status and trends for this sub-indicator is made possible by a rigorous, standardized, bird count protocol, large sample sizes, and extensive survey coverage accomplished by two bird monitoring programs operating throughout the Great Lakes. The Great Lakes Marsh Monitoring Program (GLMMP) delivered by Birds Canada, which draws upon the dedication and skills of hundreds of volunteer surveyors annually, provided much of the data used here from 1995 to 2011, as well as numerous additional data from coastal wetlands from 2011 to 2023, and all of the inland data used for comparison to coastal wetlands (Tozer, 2020, 2016). The US EPA's Great Lakes Coastal Wetland Monitoring Program (CWMP) delivered by Central Michigan University and dozens of partners in the U.S. and Canada has provided much needed expansion of coverage in coastal wetlands particularly in the northern portion of the Great Lakes since 2011 (Uzarski et al., 2017). Ongoing support of both of these programs will ensure that these high-quality data continue to be available for understanding the condition of the health of the Great Lakes ecosystem.

Assessing Data Quality

Data Characteristics	Agree	Neutral or Unknown	Disagree	Not Applicable

Data are documented, validated, or quality-assured by a recognized agency or organization	X			
Data are from a known, reliable and respected generator of data and are traceable to original sources	X			
Geographic coverage and scale of data are appropriate to the Great Lakes Basin	X			
Data obtained from sources within the U.S. are comparable to those from Canada	X			
Uncertainty and variability in the data are documented and within acceptable limits for this sub-indicator report	X			
Data used in assessment are openly available and accessible	Yes	Data are available by request here: CWMP: https://www.greatlakeswetlands.org/Home.vbhtml GLMMP: https://naturecounts.ca/nc/default/main.jsp		

Notes on Accessing Data

CWMP: Click on “complete and submit the request form” to create a new user account and request access to the data. You must be a registered user with an account to download data from the site.

GLMMP: scroll down to “Access Data,” and follow either the option to “Download Raw Data” or the “NatureCounts R package.” You must have a NatureCounts account to access data from the site or through the R package.

Data Limitations

This sub-indicator may be more powerful if evaluated as part of an overall analysis of biological communities of Great Lakes coastal wetlands and nearshore aquatic systems. This can be done by considering the coastal wetland sub-indicators in combination because they function and indicate anthropogenic disturbance at different spatial and temporal scales and have varying resolution of detection.

Great Lakes coastal wetlands are diverse. Some are protected from wind and wave action; some are open to the lake. Some are associated with river mouths, others are not. Additional variation is imposed by underlying geomorphology and meteorological differences across different regions and by human impacts. This variation in wetland types carries over to influence wetland birds. Thus, the most powerful data for estimating bird-based indices of ecosystem health at broad scales, such as across individual Great Lakes basins, are those collected via spatially-balanced randomized experimental designs, which account for and capture this variation. Most, but not all, of the existing wetland bird datasets suitable for use with this sub-indicator address these sampling issues in

their experimental designs, although there is room for improvement.

The status and trend assessment of coastal wetland health based on wetland birds utilized BR functions developed using CWMP data only. The BR functions were also developed based on information from multiple stressor gradients related to development, agriculture, and road density. The ability of the IBC to capture the health of coastal wetlands based on bird data might be improved by expanding the development of the BR functions to include all of the wetland bird data that are available from the GLMMP and CWMP, which would include data from inland wetlands. The performance of the IBC might also be improved by incorporating other known wetland bird stressors in the development of BR functions, particularly within-wetland attributes like relative dominance of invasive plant species such as *Phragmites* and *Typha* spp. These ideas are fruitful areas for future expansion.

Two large wetland bird datasets were brought together, specifically the GLMMP and CWMP datasets, to perform the analyses summarized in this report. This provided tremendous analytical power at many different scales compared to using only one of the datasets. However, it was evident that the combined dataset is deficient in information from healthy wetlands. Future collection of bird data from wetlands located towards the pristine end of the degraded-pristine gradient might improve the performance of the IBC.

IBC values were calculated for individual sample points, and these values were averaged for wetlands where more than one point was sampled. Averaging point-level samples implicitly assumes that the character of wetlands is uniform, which likely is not the case, especially for large wetlands that cover multiple wetland zones (Dybiec et al., 2020). Howe et al. (2023) described an alternative method for IBC calculations that combines point-level results for all point counts within a wetland. This method invariably yields higher IBC values for larger wetlands because the multiple points usually cover different vegetation zones or localized populations within the wetland. In most cases, large wetlands also yield relatively high point-level IBC values, but this alternative site-level approach might complement the results presented here.

Additional Information

Over half of all Great Lakes coastal wetlands have been lost due to conversion to other land uses, and remaining coastal wetlands have been changed by human activities and suffer from anthropogenic stressors, such as nutrient and sediment loading, fragmentation, invasive species, shoreline alteration, and water-level control (Land Cover sub-indicator; Amani et al., 2022; Michaud et al., 2022). Such wetland loss and stress are especially apparent in certain developed portions of the Great Lakes basin (Figure 6; Allan et al., 2013; Bourgeau-Chavez et al., 2015).

One approach to improve the health of Great Lakes coastal wetlands is to identify factors that promote occupancy or increase abundance of wetland bird species in coastal wetlands. Factors that are positively related to occupancy or abundance of wetland birds then translate into actions and opportunities that ultimately help improve wetland health. This approach has been completed using components of the larger dataset analyzed in this report, i.e., data from 10,000s of GLMMP and/or CWMP point counts have been used to determine important local, wetland, and landscape-scale factors influencing occupancy or abundance of over a dozen wetland bird species in coastal and inland wetlands throughout different parts of the Great Lakes basin (Elliott et al., 2023; Gnass Giese et al., 2018; Grand et al., 2020; Grandmaison and Niemi, 2007; Hohman et al., 2021; Jung et al., 2020; Panci et al., 2017; Studholme et al., 2023; Tozer, 2016; Tozer et al., 2024, 2020; Tozer and Mackenzie, 2019). The results of these studies suggest that multiple wetland-breeding bird species will benefit from the protection and restoration of large Great Lakes coastal wetlands or wetland complexes, which contain diverse communities of native marsh vegetation interspersed with numerous open-water pools, and which are surrounded by low amounts of urban land use in the surrounding watershed or landscape. These actions will increase occupancy or abundance, or

promote colonization or reduce local extinction of wetland birds within coastal wetlands. These actions will also ultimately help improve associated coastal wetland health across the southern portion of the Great Lakes basin.

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References

Allan, J.D., McIntyre, P.B., Smith, S.D.P., Halpern, B.S., Boyer, G.L., Buchsbaum, A., Burton, G.A., Campbell, L.M., Chadderton, W.L., Ciborowski, J.J.H., Doran, P.J., Eder, T., Infante, D.M., Johnson, L.B., Joseph, C.A., Marino, A.L., Prusevich, A., Read, J.G., Rose, J.B., Rutherford, E.S., Sowa, S.P., Steinman, A.D., 2013. Joint analysis of stressors and ecosystem services to enhance restoration effectiveness. Proc Natl Acad Sci 110, 372–377. https://doi.org/10.1073/pnas.1213841110

Amani, M., Kakooei, M., Ghorbanian, A., Warren, R., Mahdavi, S., Brisco, B., Moghimi, A., Bourgeau-Chavez, L., Toure, S., Paudel, A., Sulaiman, A., Post, R., 2022. Forty years of wetland status and trends analyses in the Great Lakes using landsat archive imagery and Google Earth engine. Remote Sensing 14, 3778. https://doi.org/10.3390/rs14153778

Anderson, O., Harrison, A., Heumann, B., Godwin, C., Uzarski, D., 2023. The influence of extreme water levels on coastal wetland extent across the Laurentian Great Lakes. Sci Total Environ 885, 163755. https://doi.org/10.1016/j.scitotenv.2023.163755

Bianchini, K., Tozer, D.C., 2023. Using Breeding Bird Survey and eBird data to improve marsh bird monitoring abundance indices and trends. Avian Conserv Ecol 18. https://doi.org/10.5751/ACE-02357-180104

Bolenbaugh, J.R., Krementz, D.G., Lehnen, S.E., 2011. Secretive marsh bird species co-occurrences and habitat associations across the Midwest, USA. J Fish Wildl Manag 2, 49–60. https://doi.org/10.3996/012011-JFWM-001

Bourgeau-Chavez, L., Endres, S., Battaglia, M., Miller, M.E., Banda, E., Laubach, Z., Higman, P., Chow-Fraser, P., Marcaccio, J., 2015. Development of a bi-national Great Lakes coastal wetland and land use map using

three-season PALSAR and Landsat imagery. Remote Sens 7, 8655–8682. https://doi.org/10.3390/rs70708655

Brackney, A., Bookhout, T., 1982. Population ecology of Common Gallinules in southwestern Lake Erie marshes. Ohio J Sci 82, 229–237.

Brazner, J.C., Danz, N.P., Niemi, G.J., Regal, R.R., Trebitz, A.S., Howe, R.W., Hanowski, J.M., Johnson, L.B., Ciborowski, J.J.H., Johnston, C.A., Reavie, E.D., Brady, V.J., Sgro, G.V., 2007a. Evaluation of geographic, geomorphic and human influences on Great Lakes wetland indicators: A multi-assemblage approach. Ecol Indic 7, 610–635. https://doi.org/10.1016/j.ecolind.2006.07.001

Brazner, J.C., Danz, N.P., Trebitz, A.S., Niemi, G.J., Regal, R.R., Hollenhorst, T., Host, G.E., Reavie, E.D., Brown, T.N., Hanowski, J.M., Johnston, C.A., Johnson, L.B., Howe, R.W., Ciborowski, J.J.H., 2007b. Responsiveness of Great Lakes wetland indicators to human disturbances at multiple spatial scales: a multi-assemblage assessment. J Great Lakes Res, Coastal Indicators 33, 42–66. https://doi.org/10.3394/0380-1330(2007)33[42:ROGLWI]2.0.CO;2

Canty, A., Ripley, B., 2013. Package boot. https://cran.r-project.org/web/packages/boot/boot.pdf.

Chin, A.T.M., Tozer, D.C., Fraser, G.S., 2014. Hydrology influences generalist–specialist bird-based indices of biotic integrity in Great Lakes coastal wetlands. J Great Lakes Res 40, 281–287. https://doi.org/10.1016/j.jglr.2014.02.006

Chin, A.T.M., Tozer, D.C., Walton, N.G., Fraser, G.S., 2015. Comparing disturbance gradients and bird-based indices of biotic integrity for ranking the ecological integrity of Great Lakes coastal wetlands. Ecol Indic 57, 475–485. https://doi.org/10.1016/j.ecolind.2015.05.010

Chun, C.L., Kahn, C.I., Borchert, A.J., Byappanahalli, M.N., Whitman, R.L., Peller, J., Pier, C., Lin, G., Johnson, E.A., Sadowsky, M.J., 2015. Prevalence of toxin-producing Clostridium botulinum associated with the macroalga Cladophora in three Great Lakes: Growth and management. Science Tot Env 511, 523–529. https://doi.org/10.1016/j.scitotenv.2014.12.080

Conway, C.J., 2011. Standardized North American marsh bird monitoring protocol. Waterbirds 34, 319–346. https://doi.org/10.1675/063.034.0307

Croft-White, M.V., Cvetkovic, M., Rokitnicki-Wojcik, D., Midwood, J.D., Grabas, G.P., 2017. A shoreline divided: Twelve-year water quality and land cover trends in Lake Ontario coastal wetlands. J Great Lakes Res 43, 1005–1015. https://doi.org/10.1016/j.jglr.2017.08.003

Crosbie, B., Chow-Fraser, P., 1999. Percentage land use in the watershed determines the water and sediment quality of 22 marshes in the Great Lakes basin. Can J Fish Aquat Sci 56, 1781–1791. https://doi.org/10.1139/f99-109

Danz, N.P., Niemi, G.J., Regal, R.R., Hollenhorst, T., Johnson, L.B., Hanowski, J.M., Axler, R.P., Ciborowski, J.J.H., Hrabik, T., Brady, V.J., Kelly, J.R., Morrice, J.A., Brazner, J.C., Howe, R.W., Johnston, C.A., Host, G.E., 2007. Integrated measures of anthropogenic stress in the U.S. Great Lakes Basin. Env Manag 39, 631–647. https://doi.org/10.1007/s00267-005-0293-0

Denomme-Brown, S.T., Fiorino, G.E., Gehring, T.M., Lawrence, G.J., Tozer, D.C., Grabas, G.P., 2023. Marsh birds as ecological performance indicators for Lake Ontario outflow regulation. J Great Lakes Res 49, 479–490. https://doi.org/10.1016/j.jglr.2023.02.001

Desgranges, J.-L., Ingram, J., Drolet, B., Morin, J., Savage, C., Borcard, D., 2006. Modelling wetland bird response to water level changes in the Lake Ontario – St. Lawrence River hydrosystem. Environ Monit Assess 113, 329–365. https://doi.org/10.1007/s10661-005-9087-3

Dinehart, R.M., Brewer, D.E., Gehring, T.M., Pangle, K.L., Uzarski, D.G., 2023. Ecologically scaled responses of marsh birds to invasive Phragmites expansion and water-level fluctuations. Waterbirds 45, 225–236. https://doi.org/10.1675/063.045.0302

Dybiec, J.M., Albert, D.A., Danz, N.P., Wilcox, D.A., Uzarski, D.G., 2020. Development of a preliminary vegetation-based indicator of ecosystem health for coastal wetlands of the Laurentian Great Lakes. Ecol Indic 119, 106768. https://doi.org/10.1016/j.ecolind.2020.106768

Elliott, L., 2019. Habitat associations and conservation of wetland-obligate birds (PhD thesis). University of Minnesota, Duluth, Minnesota, USA.

Elliott, L.H., Bracey, A.M., Niemi, G.J., Johnson, D.H., Gehring, T.M., Gnass Giese, E.E., Fiorino, G.E., Howe, R.W., Lawrence, G.J., Norment, C.J., Tozer, D.C., Igl, L.D., 2023. Application of habitat association models across regions: Useful explanatory power retained in wetland bird case study. Ecosphere 14, e4499. https://doi.org/10.1002/ecs2.4499

Environment Canada, 2002. Where land meets water: understanding wetlands of the Great Lakes. Environment Canada, Toronto, Ontario, Canada.

Getchell, R.G., Bowser, P.R., 2006. Ecology of type E botulism within Dreissenid mussel beds. Aquat Invaders 17, 1–8.

Gnass Giese, E.E., Howe, R.W., Wolf, A.T., Miller, N.A., Walton, N.G., 2015. Sensitivity of breeding birds to the "human footprint" in western Great Lakes forest landscapes. Ecosphere 6, art90. https://doi.org/10.1890/ES14-00414.1

Gnass Giese, E.E., Howe, R.W., Wolf, A.T., Niemi, G.J., 2018. Breeding birds and anurans of dynamic coastal wetlands in Green Bay, Lake Michigan. J Great Lakes Res 44, 950–959. https://doi.org/10.1016/j.jglr.2018.06.003

Grabas, G.P., Blukacz-Richards, E.A., Pernanen, S., 2012. Development of a submerged aquatic vegetation community index of biotic integrity for use in Lake Ontario coastal wetlands. J Great Lakes Res 38, 243–250. https://doi.org/10.1016/j.jglr.2012.02.014

Grabas, G.P., Rokitnicki-Wojcik, D., 2015. Characterizing daily water-level fluctuation intensity and water quality relationships with plant communities in Lake Ontario coastal wetlands. J Great Lakes Res 41, 136–144. https://doi.org/10.1016/j.jglr.2014.12.019

Grand, J., Saunders, S.P., Michel, N.L., Elliott, L., Beilke, S., Bracey, A., Gehring, T.M., Gnass Giese, E.E., Howe, R.W., Kasberg, B., Miller, N., Niemi, G.J., Norment, C.J., Tozer, D.C., Wu, J., Wilsey, C., 2020. Prioritizing coastal wetlands for marsh bird conservation in the U.S. Great Lakes. Biol Conserv 249, 108708. https://doi.org/10.1016/j.biocon.2020.108708

Grandmaison, D.D., Niemi, G.J., 2007. Local and Landscape Influence on Red-winged Blackbird (*Agelaius phoeniceus*) Nest Success in Great Lakes Coastal Wetlands. J Great Lakes Res, Coastal Indicators 33, 292–304. https://doi.org/10.3394/0380-1330(2007)33[292:LALIOR]2.0.CO;2

Gray, D.M., 1990. Usage summary for selected optimization routines, Computing science technical report No. 153, 1-21. AT&T Bell Laboratories, Murray Hill, New Jersey, USA.

Gronewold, A.D., Do, H.X., Mei, Y., Stow, C.A., 2021. A tug-of-war within the hydrologic cycle of a continental freshwater basin. Geophys Res Lett 48, e2020GL090374. https://doi.org/10.1029/2020GL090374

Gronewold, A.D., Rood, R.B., 2019. Recent water level changes across Earth's largest lake system and implications for future variability. Journal of Great Lakes Research 45, 1–3. https://doi.org/10.1016/j.jglr.2018.10.012

Hanowski, J.M., Danz, N., Howe, R., Niemi, G., Regal, R., 2007. Consideration of geography and wetland geomorphic type in the development of Great Lakes coastal wetland bird indicators. EcoHealth 4, 194–205. https://doi.org/10.1007/s10393-007-0100-x

Hartsock, J.A., Schwarting, R.J., Beaster, K., Danz, N.P., 2022. Coastal wetland plant community responses to record-high Lake Superior water levels: An Allouez Bay case study. J Great Lakes Res 48, 828–836. https://doi.org/10.1016/j.jglr.2022.02.001

Hohman, T.R., Howe, R.W., Tozer, D.C., Gnass Giese, E.E., Wolf, A.T., Niemi, G.J., Gehring, T.M., Grabas, G.P., Norment, C.J., 2021. Influence of lake levels on water extent, interspersion, and marsh birds in Great Lakes coastal wetlands. J Great Lakes Res 47, 534–545. https://doi.org/10.1016/j.jglr.2021.01.006

Howe, R.W., Niemi, G.J., Bracey, A.M., Brady, V., Elliott, L., Fiorino, G.E., Gaul, W., Gehring, T.M., Gnass Giese, E.E., Lawrence, G., Norment, C.J., Panci, H., Tozer, D.C., Uzarski, D., Walton, N.G., Wheelock, B., 2023. An Index of biotic condition (IBC) using birds as indicators of coastal wetland quality in North America's Laurentian Great Lakes. Ecol Appl 156, 111174. https://doi.org/10.1016/j.ecolind.2023.111174

Howe, R.W., Regal, R.R., Hanowski, J., Niemi, G.J., Danz, N.P., Smith, C.R., 2007a. An index of ecological condition based on bird assemblages in Great Lakes coastal wetlands. J Great Lakes Res, Coastal Indicators 33, 93–105. https://doi.org/10.3394/0380-1330(2007)33[93:AIOECB]2.0.CO;2

Howe, R.W., Regal, R.R., Niemi, G.J., Danz, N.P., Hanowski, J.M., 2007b. A probability-based indicator of ecological condition. Ecol Indic 7, 793–806. https://doi.org/10.1016/j.ecolind.2006.09.003

IUCN Standards and Petitions Committee, 2022. Guidelines for using the IUCN red list categories and criteria. Version 15.1. Prepared by the Standards and Petitions Committee. http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Jobin, B., Robillard, L., Latendresse, C., 2009. Response of a Least Bittern (*Ixobrychus exilis*) population to interannual water level fluctuations. Waterbirds 32, 73–80. https://doi.org/10.1675/063.032.0108

Jung, J.A., Rogers, H.N., Grabas, G.P., 2020. Refinement of an index of ecological condition for marsh bird communities in lower Great Lakes coastal wetlands. Ecol Indic 113, 106097. https://doi.org/10.1016/j.ecolind.2020.106097

Karr, J.R., Chu, E.W., 1999. Restoring life in running waters: better biological monitoring. Island Press, Washington, DC.

Kayastha, M.B., Ye, X., Huang, C., Xue, P., 2022. Future rise of the Great Lakes water levels under climate change. J Hydrol 612, 128205. https://doi.org/10.1016/j.jhydrol.2022.128205

Kovalenko, K.E., Brady, V.J., Brown, T.N., Ciborowski, J.J.H., Danz, N.P., Gathman, J.P., Host, G.E., Howe, R.W., Johnson, L.B., Niemi, G.J., Reavie, E.D., 2014. Congruence of community thresholds in response to anthropogenic stress in Great Lakes coastal wetlands. Freshw Sci 33, 958–971. https://doi.org/10.1086/676913

Lam, S., Dokoska, K., 2022. Climate change in the Great Lakes basin: summary of trends and impacts. Toronto and Region Conservation Authority, Toronto, Ontario, Canada.

Lor, S., Malecki, R.A., 2006. Breeding ecology and nesting habitat associations of five marsh bird species in western New York. Waterbirds 29, 427–436. https://doi.org/10.1675/1524-4695(2006)29[427:BEANHA]2.0.CO;2

Mayne, G., Hazen, S., Milner, G., Rivers, P., MacMillan, K., Mortsch, L., Zuzek, P., 2022. Adapting to climate change: solutions to enhance Great Lakes coastal wetland resilience. Environment and Climate Change Canada, Gatineau, Quebec, Canada.

McKee, P.M., Batterson, T.R., Dahl, T.E., Glooschenko, V., Jaworski, E., Pearce, J.B., Raphael, C.N., Whillans, T.H., LaRoe, E.T., 1992. Great Lakes aquatic habitat classification based on wetland classification systems, in: Busch, W.-D.N., Sly, P.G. (Eds.), The Development of an Aquatic Habitat Classification System for Lakes. CRC Press, Boca Raton, Florida, USA.

Michaud, W.J., Telech, J., Green, M., Daneshfar, B., Pawlowski, M., 2022. Sub-indicator: land cover, in: State of the Great Lakes 2022 Technical Report. Published by Environment and Climate Change Canada and U.S. Environmental Protection Agency.

Naugle, D.E., Higgins, K.F., Estey, M.E., Johnson, R.R., Nusser, S.M., 2000. Local and landscape-level factors influencing Black Tern habitat suitability. J Wildl Manag 64, 253–260. https://doi.org/10.2307/3802997

Panci, H.G., Niemi, G.J., Regal, R.R., Tozer, D.C., Gehring, T.M., Howe, R.W., Norment, C.J., 2017. Influence of local, landscape, and regional variables on Sedge and Marsh Wren occurrence in Great Lakes coastal wetlands. Wetlands 37, 447–459. https://doi.org/10.1007/s13157-017-0881-9

Pontee, N., 2013. Defining coastal squeeze: A discussion. Ocean Coast Manag 84, 204–207. https://doi.org/10.1016/j.ocecoaman.2013.07.010

Princé, K., Chipault, J.G., White, C.L., Zuckerberg, B., 2018. Environmental conditions synchronize waterbird mortality events in the Great Lakes. J Appl Ecol 55, 1327–1338. https://doi.org/10.1111/1365-2664.13063

R Core Team, 2024. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org.

Rehm, E.M., Baldassarre, G.A., 2007. The influence of interspersion on marsh bird abundance in New York. Wilson J Ornithol 119, 648–654.

Rutherford, R., Hartsock, J.A., Danz, N.P., 2022. Physical and plant community changes at a Lake Michigan coastal marsh related to a two-meter increase in lake level. Wetlands Ecol Manage 30, 547–560. https://doi.org/10.1007/s11273-022-09879-z

Smith, A.C., Hudson, M.-A.R., Downes, C., Francis, C.M., 2014. Estimating breeding bird survey trends and annual indices for Canada: how do the new hierarchical Bayesian estimates differ from previous estimates? Can Field-Nat 128, 119–134. https://doi.org/10.22621/cfn.v128i2.1565

Smith, I.M., Fiorino, G.E., Grabas, G.P., Wilcox, D.A., 2021. Wetland vegetation response to record-high Lake Ontario water levels. J Great Lakes Res 47, 160–167. https://doi.org/10.1016/j.jglr.2020.10.013

Smith, L.A., Chow-Fraser, P., 2010a. Implications of the species-area relationship on sampling effort for marsh birds in southern Ontario. Wetlands 30, 553–563. https://doi.org/10.1007/s13157-010-0048-4

Smith, L.A., Chow-Fraser, P., 2010b. Impacts of Adjacent Land Use and Isolation on Marsh Bird Communities. Env Manag 45, 1040–1051. https://doi.org/10.1007/s00267-010-9475-5

Snell, E., Mortsch, L., Galloway, M., 2006. Land use planning (Section 8.3), in: Mortsch, L., Ingram, J., Hebb, A., Doka, S. (Eds.), Great Lakes Coastal Wetland Communities: Vulnerabilities to Climate Change and Response to Adaptation Strategies. Published by Environment Canada, Fisheries and Oceans Canada, University of Waterloo.

Steen, D.A., Gibbs, J.P., Timmermans, S.T.A., 2006. Assessing the sensitivity of wetland bird communities to hydrologic change in the eastern Great Lakes region. Wetlands 26, 605–611. https://doi.org/10.1672/0277-5212(2006)26[605:ATSOWB]2.0.CO;2

Studholme, K.R., Fiorino, G.E., Grabas, G.P., Tozer, D.C., 2023. Influence of surrounding land cover on marsh-breeding birds: Implications for wetland restoration and conservation planning. J Great Lakes Res 49, 318–331. https://doi.org/10.1016/j.jglr.2022.12.002

Taft, J.B., Wilhelm, G.S., Ladd, D.M., Masters, L.A., 1997. Floristic quality assessment for vegetation in Illinois, a method for assessing vegetation integrity. Illinois Native Plant Society, Westville, Illinois, USA.

Timmermans, S.T.A., Badzinski, S.S., Ingram, J.W., 2008. Associations between breeding marsh bird abundances and Great Lakes hydrology. J Great Lakes Res 34, 351–364. https://doi.org/10.3394/0380-1330(2008)34[351:ABBMBA]2.0.CO;2

Tozer, D., Drake, K., Falconer, C., 2016. Modeling detection probability to improve marsh bird surveys in southern Canada and the Great Lakes states. Avian Conserv Ecol 11. https://doi.org/10.5751/ACE-00875-110203

Tozer, D.C., 2020. Great Lakes Marsh Monitoring Program: 25 years of conserving birds and frogs. Birds Canada, Port Rowan, Ontario, Canada. www.birdscanada.org/glmmp25.

Tozer, D.C., 2016. Marsh bird occupancy dynamics, trends, and conservation in the southern Great Lakes basin: 1996 to 2013. J Great Lakes Res 42, 136–145. https://doi.org/10.1016/j.jglr.2015.10.015

Tozer, D.C., 2014. Coastal wetland birds, in: State of the Great Lakes 2011. Cat No. En161-3/1-2011E-PDF. EPA 950-R-13-002. Published by Environment Canada and U.S. Environmental Protection Agency.

Tozer, D.C., Bracey, A.M., Fiorino, G.E., Gehring, T.M., Gnass Giese, E.E., Grabas, G.P., Howe, R.W., Lawrence, G.J., Niemi, G.J., Wheelock, B.A., Ethier, D.M., 2024. Increasing marsh bird abundance in coastal wetlands of the Great Lakes, 2011–2021, likely caused by increasing water levels. Ornithol Appl duad062. https://doi.org/10.1093/ornithapp/duad062

Tozer, D.C., Falconer, C., Bracey, A., Gnass Giese, E., Niemi, G., Howe, R., Gehring, T., Norment, C., 2017a. Influence of call broadcast timing within point counts and survey duration on detection probability of marsh breeding birds. Avian Conserv Ecol 12. https://doi.org/10.5751/ACE-01063-120208

Tozer, D.C., Howe, R.W., Niemi, G.J., Gnass Giese, E.E., Bracey, A.M., Fiorino, G.E., Gehring, T.M., Lawrence, G.L., Norment, C.J., 2022. Sub-indicator: coastal wetland birds, in: State of the Great Lakes 2022 Technical Report. Cat No. En161-3/1E-PDF. EPA 905-R-22-004. Published by Environment and Climate Change Canada and U.S. Environmental Protection Agency.

Tozer, D.C., Howe, R.W., Niemi, G.J., Gnass Giese, E.E., Walton, N.G., Bracey, A.M., Gaul, W., Grabas, G.P., Norment, C.J., Gehring, T.M., 2019. Sub-Indicator: coastal wetland birds, in: State of the Great Lakes 2019 Technical Report. Cat No. En161-3/1E-PDF. EPA 905-R-20-044. Published by Environment and Climate Change Canada and U.S. Environmental Protection Agency.

Tozer, D.C., Howe, R.W., Niemi, G.J., Gnass Giese, E.E., Walton, N.G., Bracey, A.M., Gaul, W., Norment, C.J., Gehring, T.M., 2017b. Sub-Indicator: coastal wetland birds, in: State of the Great Lakes 2017 Technical Report. Cat No. En161-3/1E-PDF. EPA 905-R-17-001. Published by Environment and Climate Change Canada and U.S. Environmental Protection Agency.

Tozer, D.C., Mackenzie, S.A., 2019. Control of invasive *Phragmites* increases marsh birds but not frogs. Can Wildl Biol Manage 8, 66–82.

Tozer, D.C., Nol, E., Abraham, K.F., 2010. Effects of local and landscape-scale habitat variables on abundance and reproductive success of wetland birds. Wetlands Ecol Manage 18, 679–693. https://doi.org/10.1007/s11273-010-9187-x

Tozer, D.C., Stewart, R.L.M., Steele, O., Gloutney, M., 2020. Species-habitat relationships and priority areas for marsh-breeding birds in Ontario. J Wildl Manage 84, 786–801. https://doi.org/10.1002/jwmg.21840

Uzarski, D.G., Brady, V.J., Cooper, M.J., Wilcox, D.A., Albert, D.A., Axler, R.P., Bostwick, P., Brown, T.N., Ciborowski, J.J.H., Danz, N.P., Gathman, J.P., Gehring, T.M., Grabas, G.P., Garwood, A., Howe, R.W., Johnson, L.B., Lamberti, G.A., Moerke, A.H., Murry, B.A., Niemi, G.J., Norment, C.J., Ruetz, C.R., Steinman, A.D., Tozer, D.C., Wheeler, R., O'Donnell, T.K., Schneider, J.P., 2017. Standardized measures of coastal wetland condition: implementation at a Laurentian Great Lakes basin-wide scale. Wetlands 37, 15–32. https://doi.org/10.1007/s13157-016-0835-7

Venter, O., Sanderson, E.W., Magrach, A., Allan, J.R., Beher, J., Jones, K.R., Possingham, H.P., Laurance, W.F., Wood, P., Fekete, B.M., Levy, M.A., Watson, J.E.M., 2016. Global terrestrial Human Footprint maps for 1993 and 2009. Sci Data 3, 160067. https://doi.org/10.1038/sdata.2016.67

Voigts, D.K., 1976. Aquatic invertebrate abundance in relation to changing marsh vegetation. Am Midl Nat 95, 313–322. https://doi.org/10.2307/2424396

Wyman, K.E., Cuthbert, F.J., 2017. Black tern (*Chlidonias niger*) breeding site abandonment in U.S. Great Lakes coastal wetlands is predicted by historical abundance and patterns of emergent vegetation. Wetlands Ecol Manage 25, 583–596. https://doi.org/10.1007/s11273-017-9537-z

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Table 1. Bird species and groups of species (*n* = 14) used to generate biotic response (BR) functions (Figure 1) and associated weights for calculating the Index of Biotic Condition (IBC) as a measure of the health of Great Lakes wetlands. See Index of Biotic Condition section above for how the weights were calculated.

Source: Howe et al. (2023).

Table 2. Long-term (1995–2023) and 10-year (2013–2023) trends of median Index of Biotic Condition (IBC) based on wetland birds throughout coastal and inland wetlands of the entire Great Lakes (overall) and within each basin (e.g., Superior). Shown are geometric mean rates of change (Trend: % per year) based on differences between the first and last year in the trend, along with "lower" and "upper" 95% confidence limits. Instances where sample sizes were too low to calculate reliable trends are shown with dashes. Trends calculated using equation 4 in Smith et al. (2014) with 1,000 bootstrap replicates. Statistically significant trends are shown in bold, based on confidence intervals that do not overlap zero.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

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Figure 1. Biotic response functions (lines) for bird species and groups of species used for calculating bird-based indices of wetland health, based on data from 1,557 sample points in 580 coastal wetlands throughout the Great Lakes basin. Shown is the probability of occurrence as a function of a combined "human footprint" variable (environmental condition, Cenv) describing the "human footprint" in the landscape surrounding each sample point (0 = poor condition, 10 = good condition). See Table 1 for the species that comprise groups and for scientific names.

Source: Great Lakes Coastal Wetland Monitoring Program, Howe et al. (2023).

Figure 2. Wetlands surveyed for birds from 1995 to 2023 throughout the Great Lakes basin for calculating bird-based indices of wetland health. Shown are wetlands as a function of the number of years that each wetland was surveyed (top) and as a function of coastal versus inland (bottom). Note that coastal wetlands (*n* = 1,283; 67%) far outnumber inland wetlands (*n* = 625; 33%), although this does not appear to be the case due to tightly overlapping symbols.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

Figure 3. Number of wetlands surveyed for birds per year from 1995 to 2023 throughout the Great Lakes basin for calculating bird-based indices of wetland health. Shown are wetlands surveyed as a function of the entire Great Lakes basin (overall) and each individual lake basin for coastal and inland wetlands.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

Figure 4. Temporal trends in the Index of Biotic Condition (IBC) based on bird community data from 1995 to 2023 throughout the entire Great Lakes basin (overall) and each individual lake basin for coastal (blue) and inland (orange) wetlands. Shown are box-and-whisker plots of wetland-level means in each year along with loess smoother lines of best fit (solid black lines). Whiskers represent data within 1.5 times the interquartile range; dots are outliers.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

Figure 5. Distribution of the Index of Biotic Condition (IBC) based on bird community data from the past 3 years (2021–2023) throughout the entire Great Lakes basin (overall) and each individual lake basin. Shown are box-and-

whisker plots of wetland-level means. Whiskers represent data within 1.5 times the interquartile range; dots are outliers. Vertical, dashed, grey lines show defining values for Poor, Fair, and Good status.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

Figure 6. Index of Biotic Condition (IBC) throughout coastal wetlands of the Great Lakes based on bird community data from the past 5 years (2019–2023). Shown are wetland-level mean IBCs, averaged across years for wetlands that were sampled in multiple years. The most recent 5 years of data were used to boost sample sizes.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

Figure 7. Density plots of the Index of Biotic Condition (IBC) based on bird community data from the past 5 years (2019–2023) throughout the entire Great Lakes basin (overall) and each individual lake basin for coastal and inland wetlands. Shown are probability density functions based on kernel density estimates, which can be thought of as smoothed histograms. Density plots are useful alternatives to histograms for continuous data that come from an underlying smooth distribution, as is the case here. Shown are plots based on wetland-level mean IBC values, averaged across years for wetlands that were sampled in multiple years. Inland data for lakes Superior and Michigan are not shown due to small sample sizes.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

Last Updated

State of the Great Lakes 2025 Report

Table 1. Bird species and groups of species (*n* = 14) used to generate biotic response (BR) functions (Figure 1) and associated weights for calculating the Index of Biotic Condition (IBC) as a measure of the health of Great Lakes wetlands. See Index of Biotic Condition section above for how the weights were calculated.

Source: Howe et al. (2023).

No.	Label	Species	Weight
1	Bittern	American Bittern (*Botaurus lentiginosus*) or Least Bittern (*Ixobrychus exilis*)	1.60
2	Common Yellowthroat	Common Yellowthroat (*Geothlypis trichas*)	1.96
3	Coot-Gallinule	American Coot (*Fulica americana*) or Common Gallinule (*Gallinula galeata*)	0.72
4	Dabbling duck (excluding Mallard)	American Black Duck (*Anas rubripes*), Northern Pintail (*A. acuta*), Green-winged Teal (*A. carolinensis*), American Wigeon (*Mareca americana*), Gadwall (*M. strepera*), Blue-winged Teal (*Spatula discors*), Northern Shoveler (*S. clypeata*), or Wood Duck (*Aix sponsa*); excluding Mallard (*A. platyrhynchos*)	0.89
5	Eagle-Osprey	Bald Eagle (*Haliaeetus leucocephalus*) or Osprey (*Pandion haliaetus*)	0.51
6	Grebe	Pied-billed Grebe (*Podilymbus podiceps*) or Red-necked Grebe (*Podiceps grisegena*)	6.36
7	Heron	Great Blue Heron (*Ardea herodias*), Great Egret (*A. alba*), Green Heron (*Butorides virescens*), or Black-crowned Night-Heron (*Nycticorax nycticorax*)	1.58
8	Other	Northern Harrier (*Circus hudsonius*), Wilson's Phalarope (*Phalaropus tricolor*), or Wilson's Snipe (*Gallinago delicata*)	0.88
9	Rail	Sora (*Porzana carolina*), Virginia Rail (*Rallus limicola*), King Rail (*Rallus elegans*), or Yellow Rail (*Coturnicops noveboracensis*)	0.85
10	Red-winged Blackbird	Red-winged Blackbird (*Agelaius phoeniceus*)	0.25
11	Sandhill Crane	Sandhill Crane (*Antigone canadensis*)	1.63
12	Swamp Sparrow	Swamp Sparrow (*Melospiza georgiana*)	1.81
13	Tern	Forster's Tern (*Sterna forsteri*) or Black Tern (*Chlidonias niger*); excluding Caspian Tern (*Hydroprogne caspia*) and Common Tern (*Sterna hirundo*), which are highly local, feed mostly over open water, not wetlands, and extremely rarely nest in wetlands	3.36
14	Wren	Marsh Wren (*Cistothorus palustris*) or Sedge Wren (*Cistothorus platensis*)	1.79

Table 2. Long-term (1995–2023) and 10-year (2013–2023) trends of median Index of Biotic Condition (IBC) based on wetland birds throughout coastal and inland wetlands of the entire Great Lakes (overall) and within each basin (e.g., Superior). Shown are geometric mean rates of change (Trend: % per year) based on differences between the first and last year in the trend, along with "lower" and "upper" 95% confidence limits. Instances where sample sizes were too low to calculate reliable trends are shown with dashes. Trends calculated using equation 4 in Smith et al. (2014) with 1,000 bootstrap replicates. Statistically significant trends are shown in bold, based on confidence intervals that do not overlap zero. Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

Wetland type	Basin	Start year	End year	Trend	Lower	Upper
Coastal	Overall	1995	2023	–	–	–
		2013	2023	0.7	-0.3	1.7
	Superior	1995	2023	–	–	–
		2013	2023	-1.0	-3.4	1.4
	Michigan	1995	2023	–	–	–
		2013	2023	1.9	-1.9	5.7
	Huron	1995	2023	–	–	–
		2013	2023	-0.2	-2.9	2.5
	Erie	1995	2023	0.2	-0.8	1.2
		2013	2023	-0.5	-3.0	2.0
	Ontario	**1995**	**2023**	**1.7**	**0.5**	**2.9**
		2013	2023	0.9	-0.4	2.3
Inland	Overall	1995	2023	–	–	–
		2013	2023	0.3	-1.2	1.8
	Superior	1995	2023	–	–	–
		2013	2023	–	–	–
	Michigan	1995	2023	–	–	–
		2013	2023	–	–	–
	Huron	1995	2023	1.4	-0.1	3.0
		2013	2023	0.6	-3.2	4.4
	Erie	1995	2023	1.0	-0.4	2.4
		2013	2023	-2.4	-5.6	0.7
	Ontario	1995	2023	-0.5	-1.8	0.8
		2013	2023	0.2	-1.6	2.0

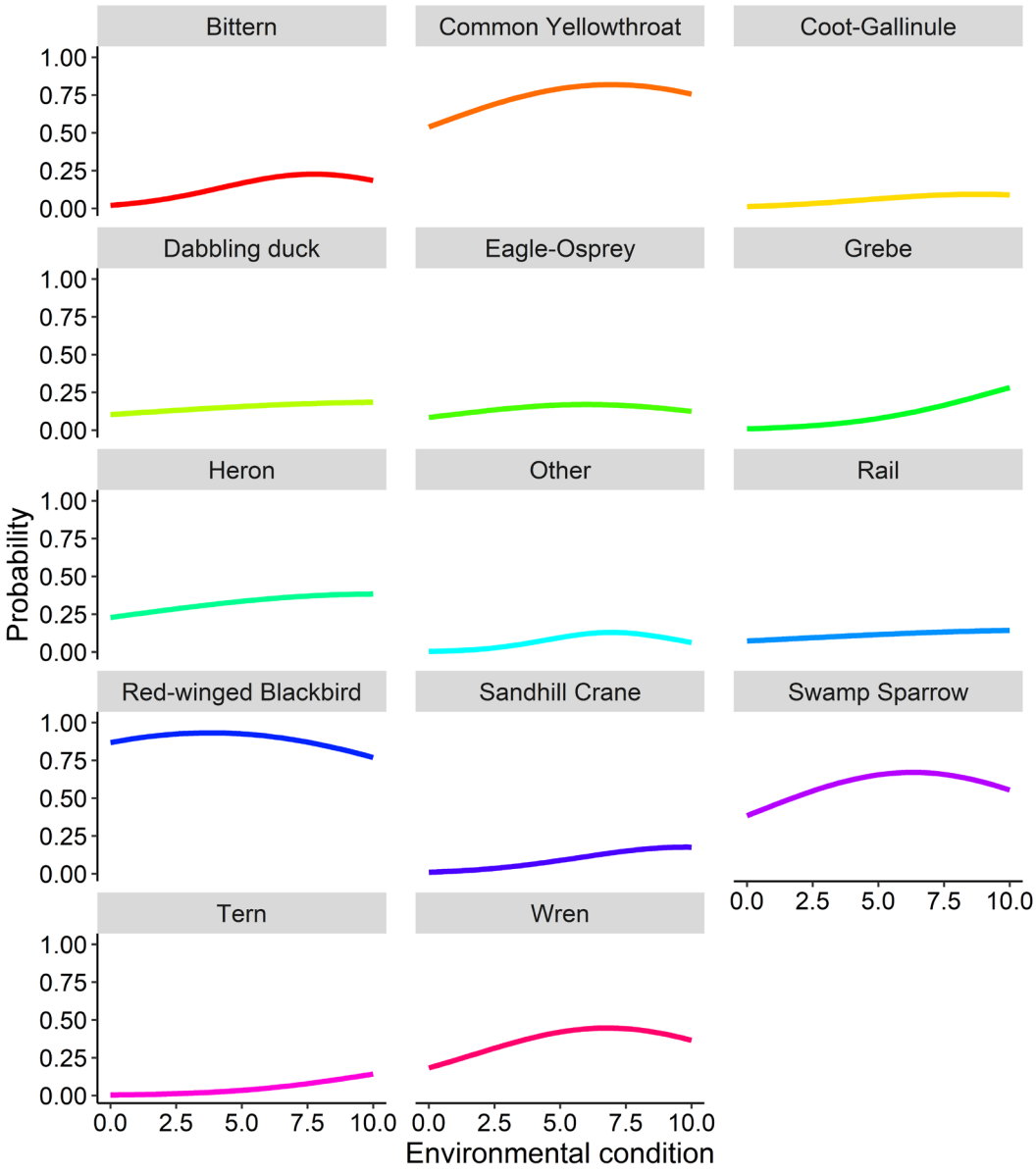


Figure 1. Biotic response functions (lines) for bird species and groups of species used for calculating bird-based indices of wetland health, based on data from 1,557 sample points in 580 coastal wetlands throughout the Great Lakes basin. Shown is the probability of occurrence as a function of a combined "human footprint" variable (environmental condition, Cenv) describing the "human footprint" in the landscape surrounding each sample point (0 = poor condition, 10 = good condition). See Table 1 for the species that comprise groups and for scientific names.

Source: Great Lakes Coastal Wetland Monitoring Program, Howe et al. (2023).

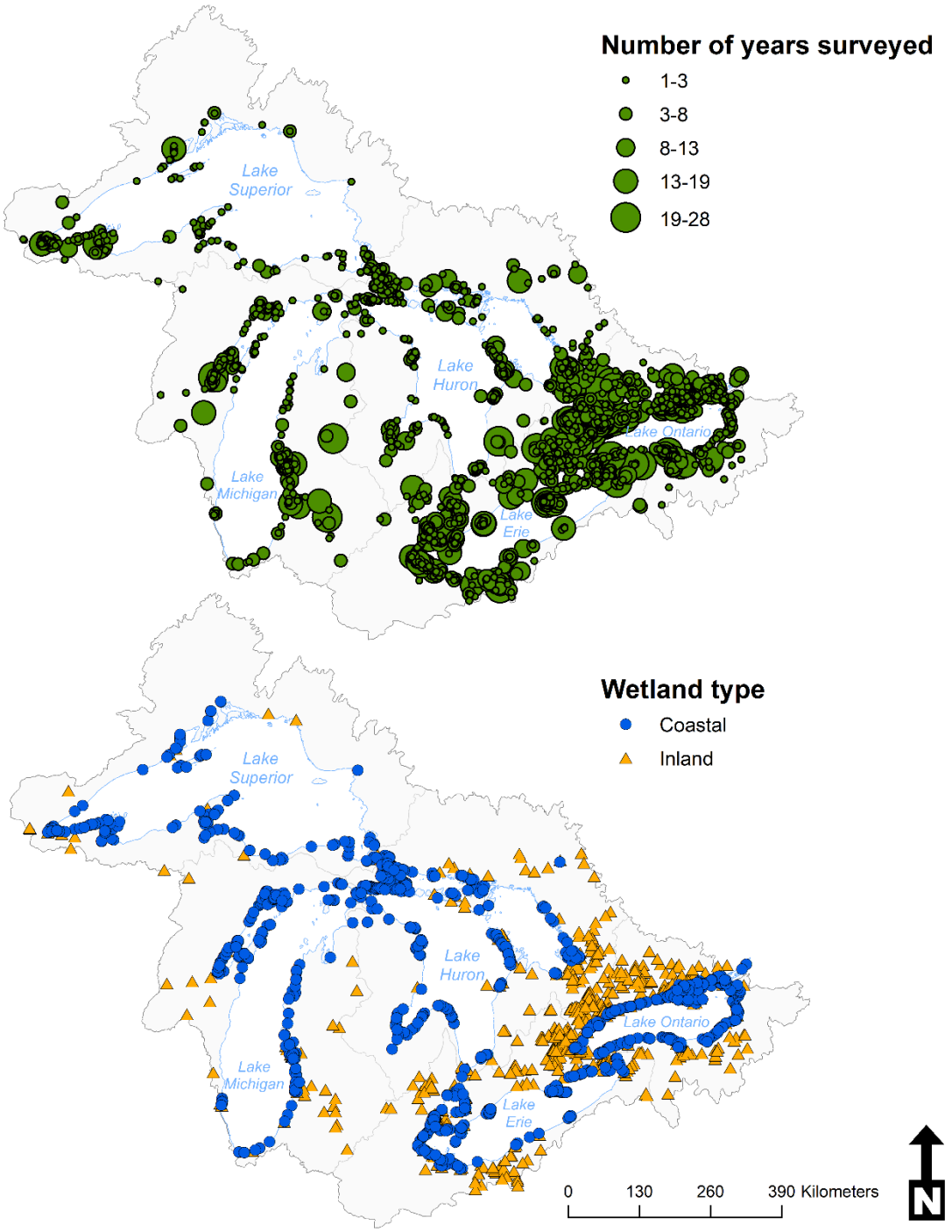


Figure 2. Wetlands surveyed for birds from 1995 to 2023 throughout the Great Lakes basin for calculating bird-based indices of wetland health. Shown are wetlands as a function of the number of years that each wetland was surveyed (top) and as a function of coastal versus inland (bottom). Note that coastal wetlands (*n* = 1,283; 67%) far outnumber inland wetlands (*n* = 625; 33%), although this does not appear to be the case due to tightly overlapping symbols.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

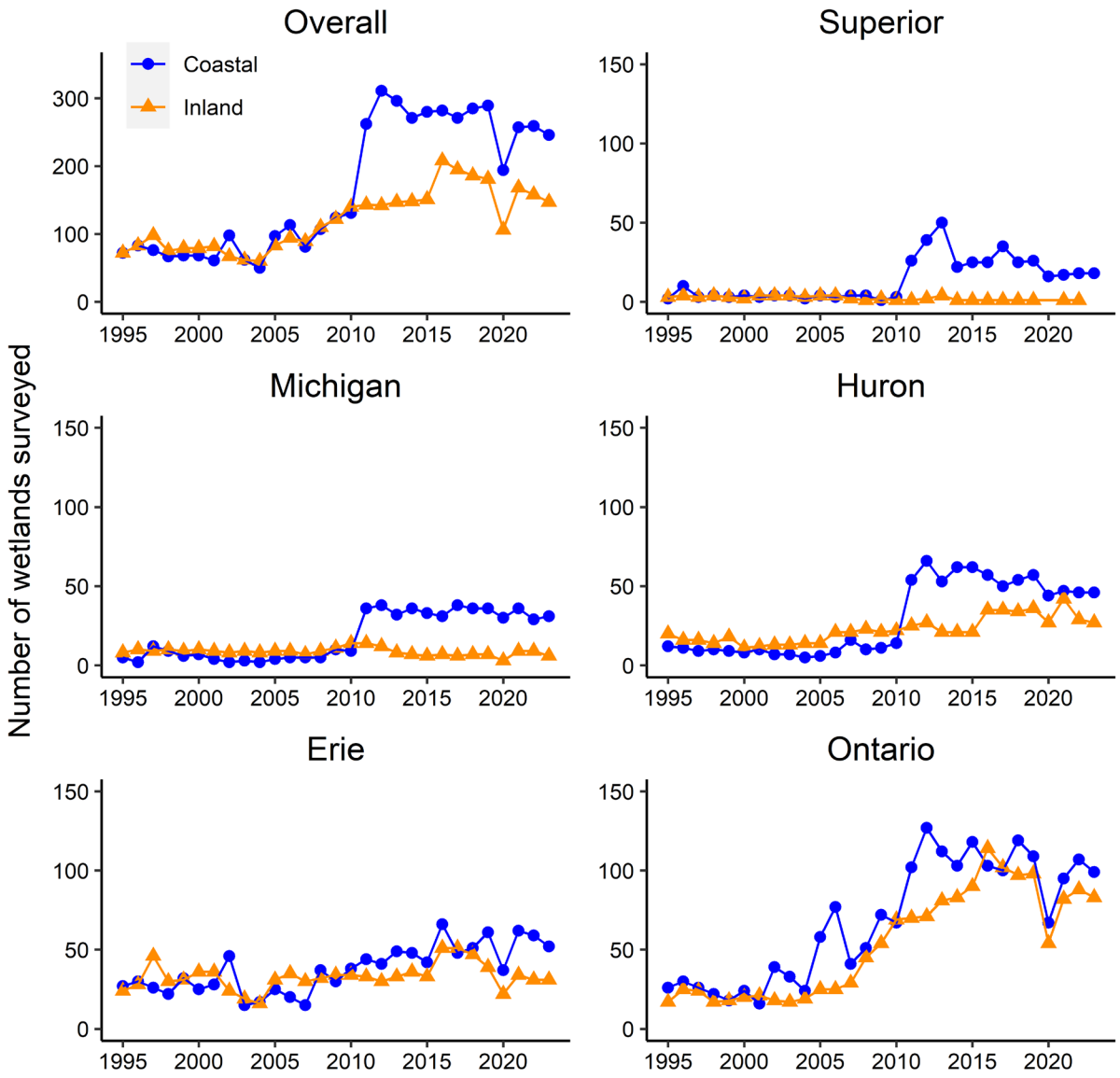


Figure 3. Number of wetlands surveyed for birds per year from 1995 to 2023 throughout the Great Lakes basin for calculating bird-based indices of wetland health. Shown are wetlands surveyed as a function of the entire Great Lakes basin (overall) and each individual lake basin for coastal and inland wetlands.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

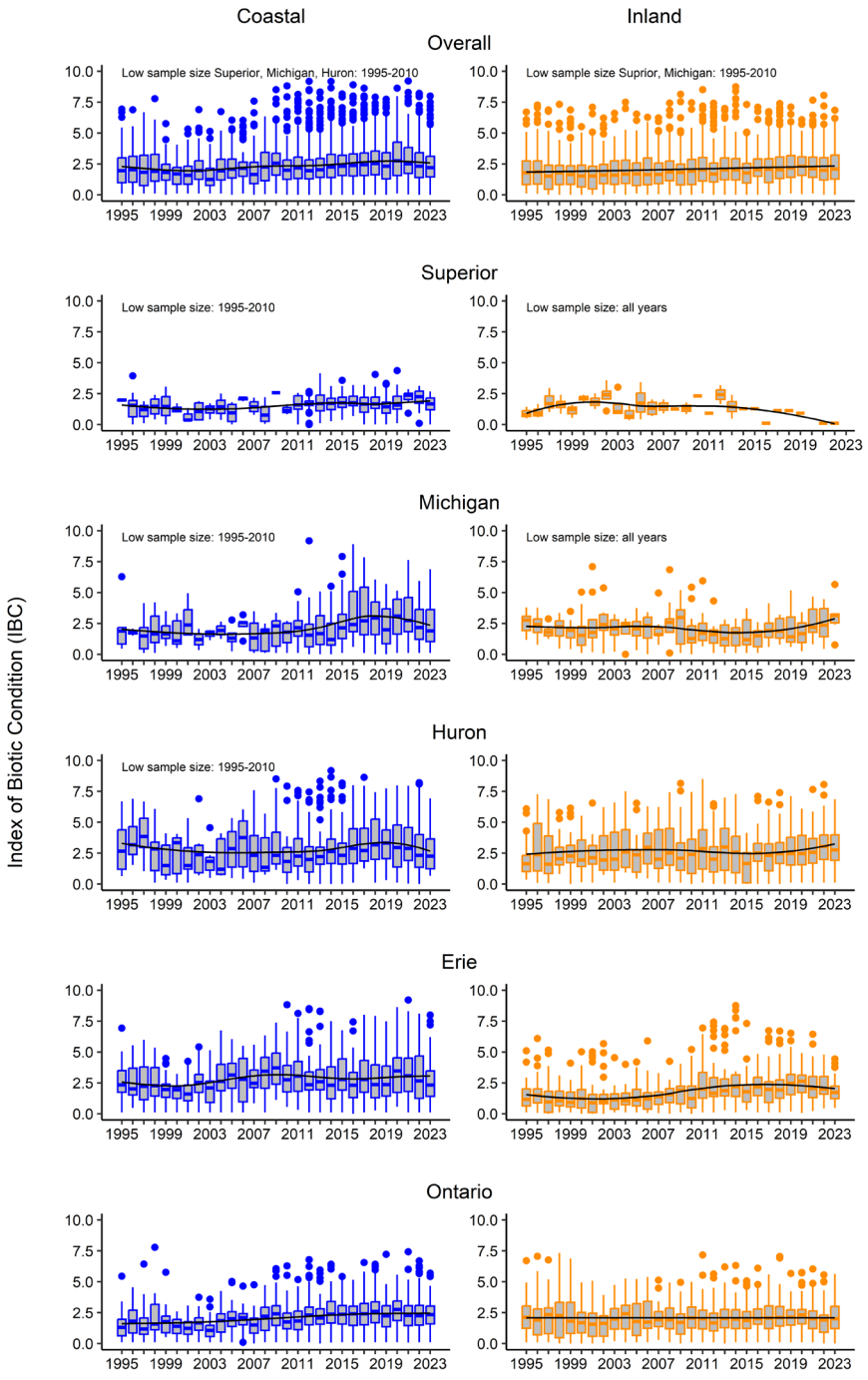
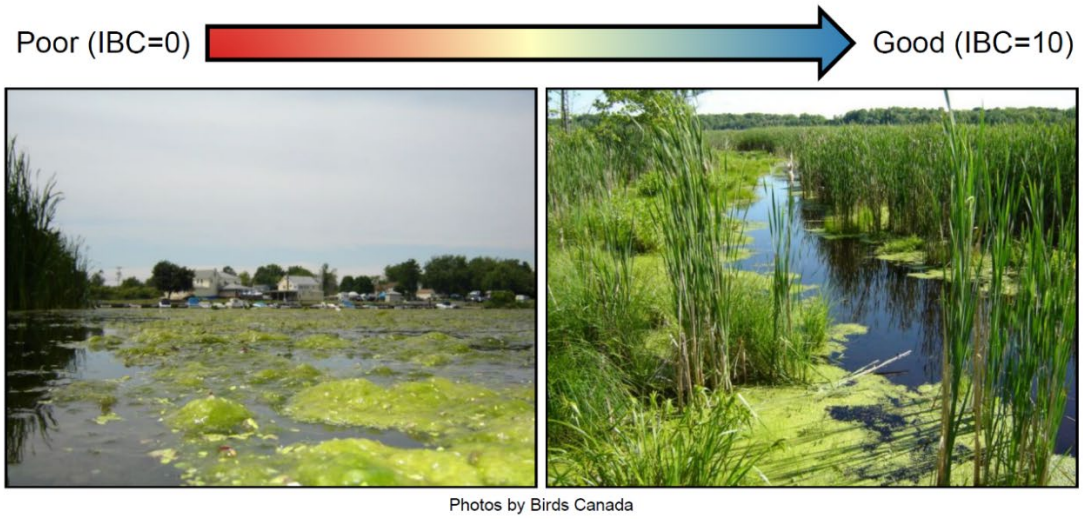


Figure 4. Temporal trends in the Index of Biotic Condition (IBC) based on bird community data from 1995 to 2023 throughout the entire Great Lakes basin (overall) and each individual lake basin for coastal (blue) and inland (orange) wetlands. Shown are box-and-whisker plots of wetland-level means in each year along with loess smoother lines of best fit (solid black lines). Whiskers represent data within 1.5 times the interquartile range; dots are outliers.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.



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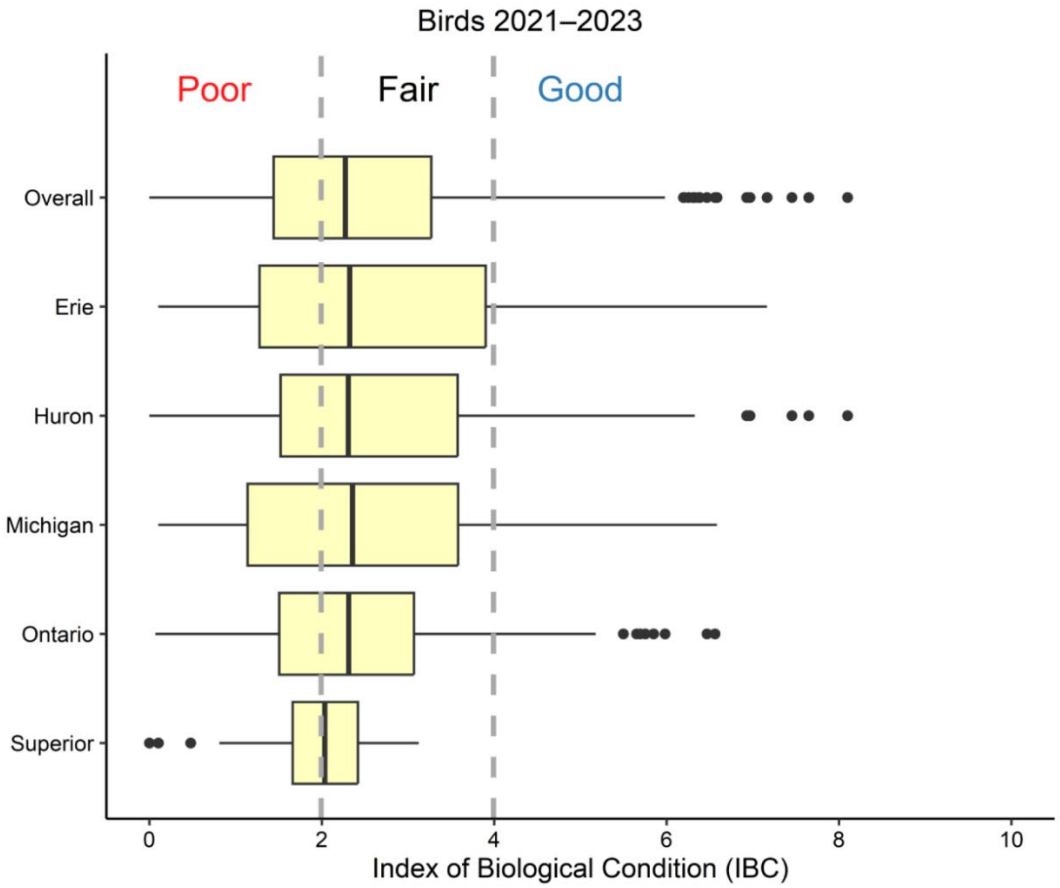

Figure 5. Distribution of the Index of Biotic Condition (IBC) based on bird community data from the past 3 years (2021–2023) throughout the entire Great Lakes basin (overall) and each individual lake basin. Shown are box-and-whisker plots of wetland-level means. Whiskers represent data within 1.5 times the interquartile range; dots are outliers. Vertical, dashed, grey lines show defining values for Poor, Fair, and Good status.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

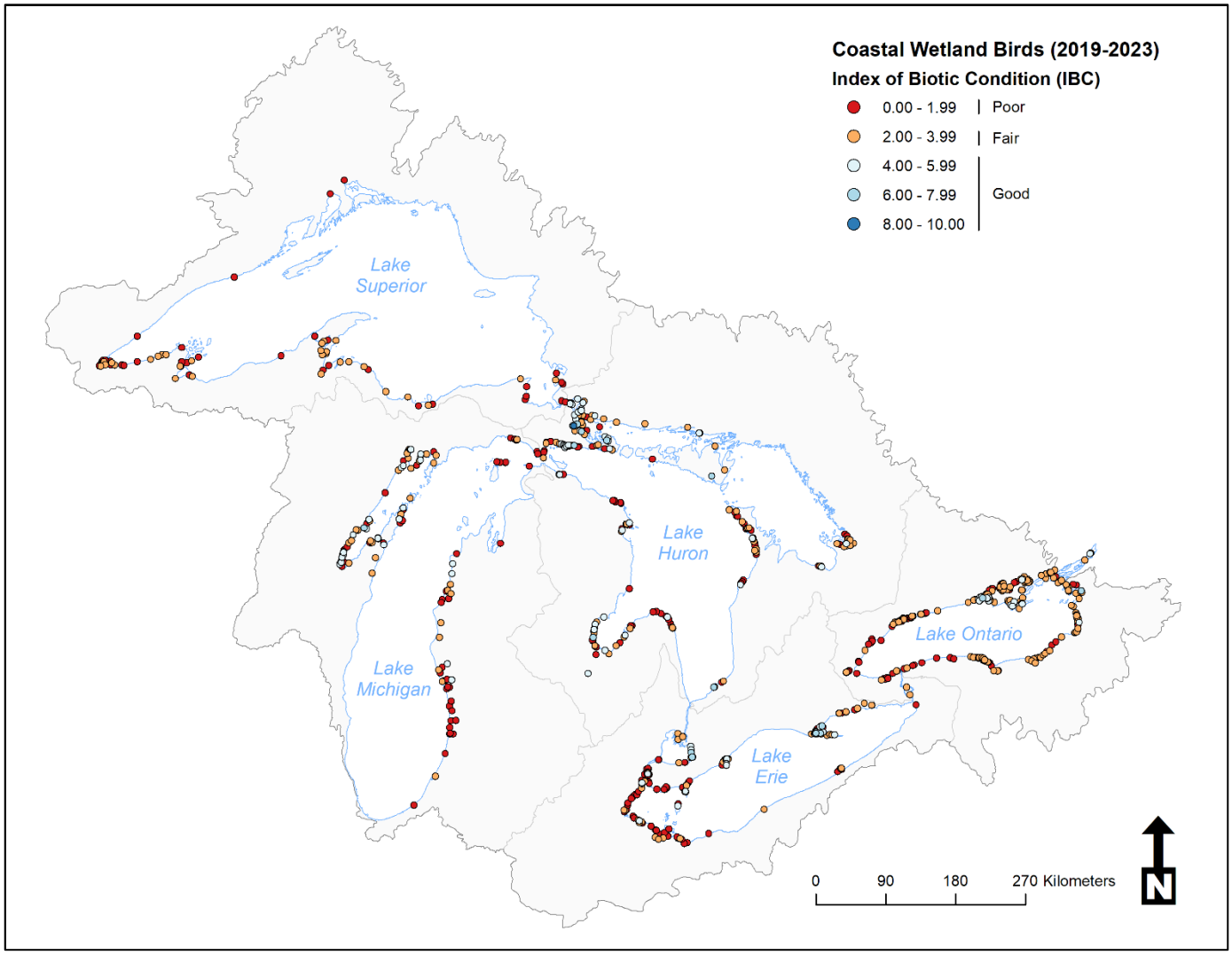

Figure 6. Index of Biotic Condition (IBC) throughout coastal wetlands of the Great Lakes based on bird community data from the past 5 years (2019–2023). Shown are wetland-level mean IBCs, averaged across years for wetlands that were sampled in multiple years. The most recent 5 years of data were used to boost sample sizes.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.

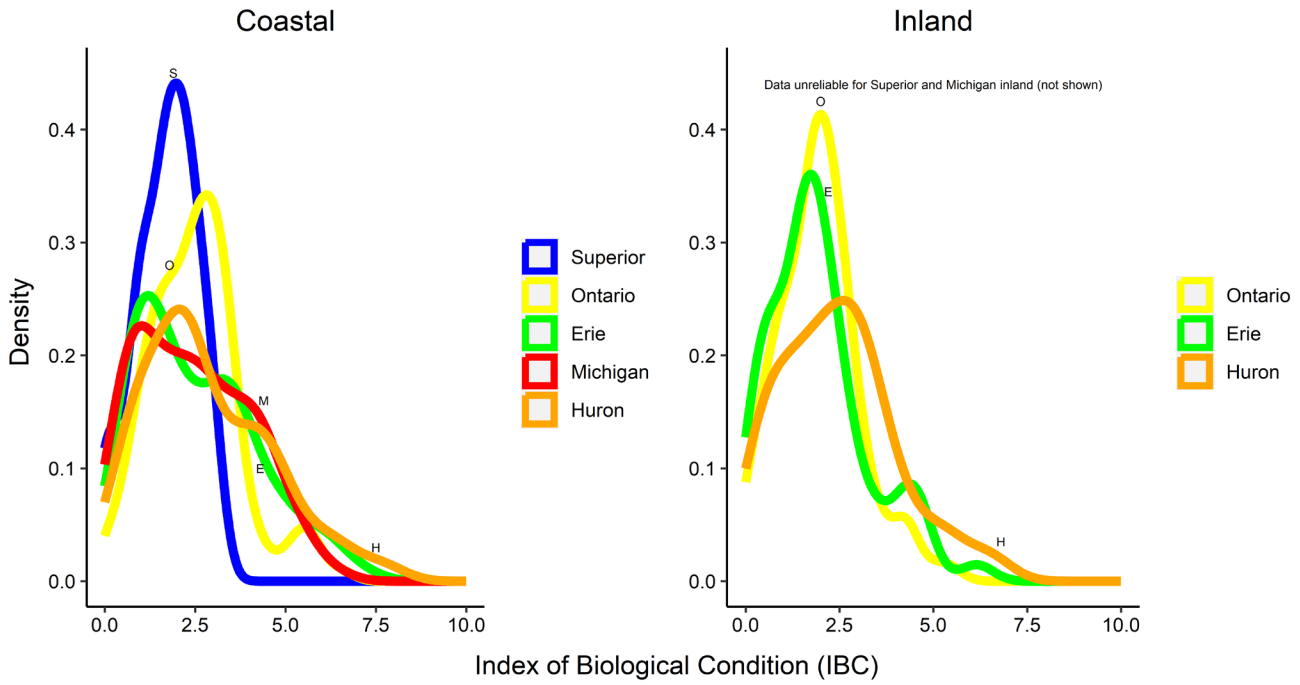

Figure 7. Density plots of the Index of Biotic Condition (IBC) based on bird community data from the past 5 years (2019–2023) throughout the entire Great Lakes basin (overall) and each individual lake basin for coastal and inland wetlands. Shown are probability density functions based on kernel density estimates, which can be thought of as smoothed histograms. Density plots are useful alternatives to histograms for continuous data that come from an underlying smooth distribution, as is the case here. Shown are plots based on wetland-level mean IBC values, averaged across years for wetlands that were sampled in multiple years. Inland data for lakes Superior and Michigan are not shown due to small sample sizes.

Source: Great Lakes Marsh Monitoring Program, Great Lakes Coastal Wetland Monitoring Program.